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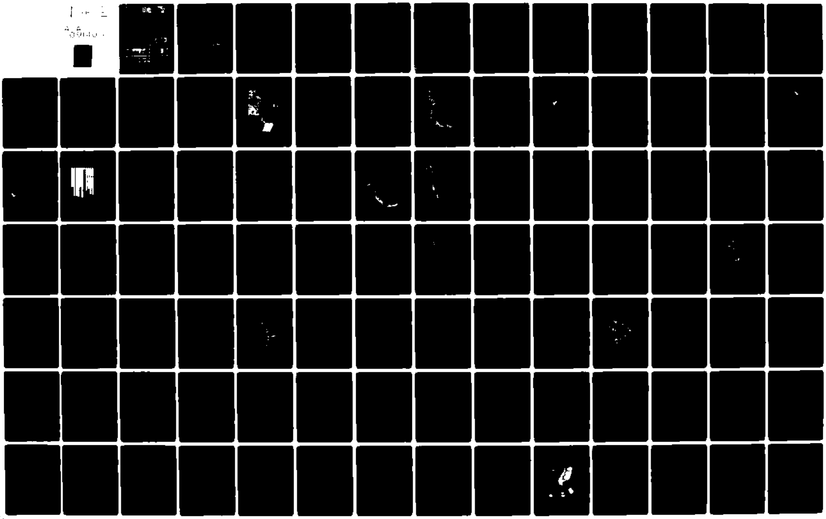

LEVEL III

GULF COAST
DEEP WATER PORT FACILITIES STUDY

Appendix A
Western Gulf Hydrobiological Zones

a report to

U.S. DEPARTMENT OF THE ARMY
VICKSBURG DISTRICT CORPS OF ENGINEERS

1 APRIL 1973

Arthur D. Little, Inc.

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Gulf Coast Deep Water Port Facilities Study

APPENDIX A

WESTERN GULF HYDROBIOLOGICAL ZONES

A report to

U.S. Department of the Army
Vicksburg District Corps of Engineers
Vicksburg, Mississippi 39108

prepared under

15 Contract No. DACW 38-73-C-0027

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INTRODUCTION

The Gulf of Mexico has a surface area of approximately 619,000 square miles, and is connected with the Caribbean Sea by the Yucatan Channel (100 miles wide and 1000 fathoms deep) and with the Atlantic Ocean by the Florida Straits, which is less than 100 miles wide and only 440 fathoms deep. Thus, the combined width of both channels is less than two percent of the Gulf's perimeter, not considering bays and islands. No small part of the characteristics of the Gulf in general and of the western Gulf in particular are attributable to the fact that both of these connections with the parent Atlantic are confined to the southeastern sector.

In the 18 counties of Texas adjoining the coast there are estimated to be 622 square miles of coastal marsh and at least 2100 square miles of bays and estuaries. The latter add dramatically to the length of the interface between land and sea. Thus, although the direct distance from the Texas-Louisiana border to its junction with Mexico is 370 miles, the circuitous route is conservatively estimated to be nearly six times this figure. Up to now these embayments have been stressed primarily by terrigenous wastes introduced by air currents and fresh water runoff. Tomorrow these bays face new hazards from the open Gulf in increasing numbers. The severity of these hazards can be lessened by thoughtful planning and by strict adherence to careful modes of operation of offshore facilities of all types.

Fortunately, nature has provided some safeguards against pollution from the sea in that most of the lagoons and bays are protected by 300 miles of barrier islands and peninsulas with less than a dozen interconnecting passes to the sea.

Three environmental factors appear to us to be of prime importance when considering the problem of selecting a compromise site for installation of a terminal that will handle bulk crudes. Spotlighting them is based on the assumption that all are agreed that the estuaries must be preserved if at all possible, and that once the protective barrier into the lagoons is breached cleansing will take an inordinately long time. The environmental factors are:

Winds and wind stress regimes – important because winds (a) determine currents, (b) propel some oil films faster than the burdened water, (c) thus determine where an oil mass is likely to make landfall and when it will get there, (d) hasten evaporation of some fractions of crudes, (e) promote mixing and thus dissolution of other factors, thereby (f) determining the relative danger of the pollutant to animal and plant life en route from origin to destination, and (g) modifying the toxicity and final fate of the product that reaches the shore.

Water temperature – because it will (a) determine rates of evaporation and weathering of some components of crudes, (b) determine some characteristics of oil films, and (c) may control bacterial metabolism, which may aid in removal of some hydrocarbons associated with spills.

River runoff into embayments – this factor may be more important than first estimates suggest. Substantial runoff can and does create differential water levels that favor net surface water transport gulfward through the passes, forming a water barrier under normal wind conditions.

Much of the information in the following pages points to the inescapable conclusion, viz., that the estuaries of Texas are the fragile link in an environmental system that provides man with appealing and nutritious food products, including waterfowl, with a storehouse of recreational pleasures and scientific pursuits.

There is no "best" way to quantitate the value of the complex resource represented by embayments. For what it is worth to specialists in the field of finance, one attempt at evaluation is given here at the outset. Starting with a report by the Bureau of Business Research, University of Texas ("Marine Resources of the Corpus Christi Area"), which in 1958 placed an annual value of $370 on each surface acre of Corpus Christi and Aransas Bays, Lockwood, Andrews and Newman, Inc. (1967) calculated that the 1.3 million acres of Texas bays would have an annual value of $483 million. Taking this as an annuity of $483 million per year at 5.0 percent for 50 years, they concluded that these bays were worth $8.8 billion or $6780 per acre.

Used wisely the Gulf can remain viable while meeting reasonable needs of modern society.

I. ESTUARIES, BAYS, AND LAGOONS
(ZONES I, II, AND III)

A. INTRODUCTION

Behind the beach line of the narrow, curvilinear, barrier islands of Texas there are at least a million and a third acres of shallow bays. For a long time these estuaries and lagoons have been receiving steadily increasing waste discharges from the land. With little tidal flux and often small exchange of water with the Gulf of Mexico, the input of rivers and Gulf tides and waste flows are concentrated by evaporation and stirred by steady winds to create new physico-chemical regimes that cause important shifts in the ecosystem. Fortunately, awareness is becoming more general among those who perform major manipulations on the coastal lands of Texas that we have no penetrating conception of how close we are to the point of no return, that is, when the magnificent biomachine that transforms the electromagnetic energy of the sun into a brown shrimp, a blue crab or a red fish comes to a silent halt.

The Texas Coastal Zone, which embraces these waterways, includes 1800 miles of bay and Gulf shorelines adjacent to 20,000 square miles of coastal lands some 40 miles in width.

Flawn (1972) estimates that products of commercial fisheries retail at $200,000,000 per year, and the fertile soils of the Zone produce agricultural products valued at $500,000,000 per year. The beaches and waters of the Coastal Zone are a recreation resource that attracts large numbers of tourists and sports fishermen. According to Flawn (1972) 3,000,000 tourists spend nearly $200,000,000 per year in the Texas coastal region. About one-quarter of the state's population and one-third of its economic resources are concentrated in a zone that encompasses no more than 6 percent of the state's area (Fisher et al., 1972).

There are eight major embayments (Figure A-1) along the Texas coast from the lower Laguna Madre on the south to Sabine Lake on the northeast coast. From south to north and east, in addition to lower Laguna Madre, there are upper Laguna Madre, Corpus Christi Bay, Aransas Bay, San Antonio Bay, Matagorda Bay, Galveston Bay, and Sabine Lake. With the exception of the Laguna Madre, these embayments consist of true estuaries, bays, and lagoons. At various places in the report the embayments will be named for the principal rivers: to wit, the Guadalupe River Estuary, of which San Antonio Bay is a most important part. Each of these in turn may be subdivided into one or more estuaries, bays, lagoons or passes. In addition two major rivers, the Brazos and the Colorado, empty more or less directly into the Gulf. All of the estuarine systems, except the Sabine-Neches, are separated from the Gulf of Mexico by one or more barrier islands, the longest of which is Padre Island that protects the Laguna Madre for well over 100 miles.

Combined with these natural coastal environments are bay-side and intrabay oil fields, bay-side refineries and petrochemical plants, dredged intracoastal canals and

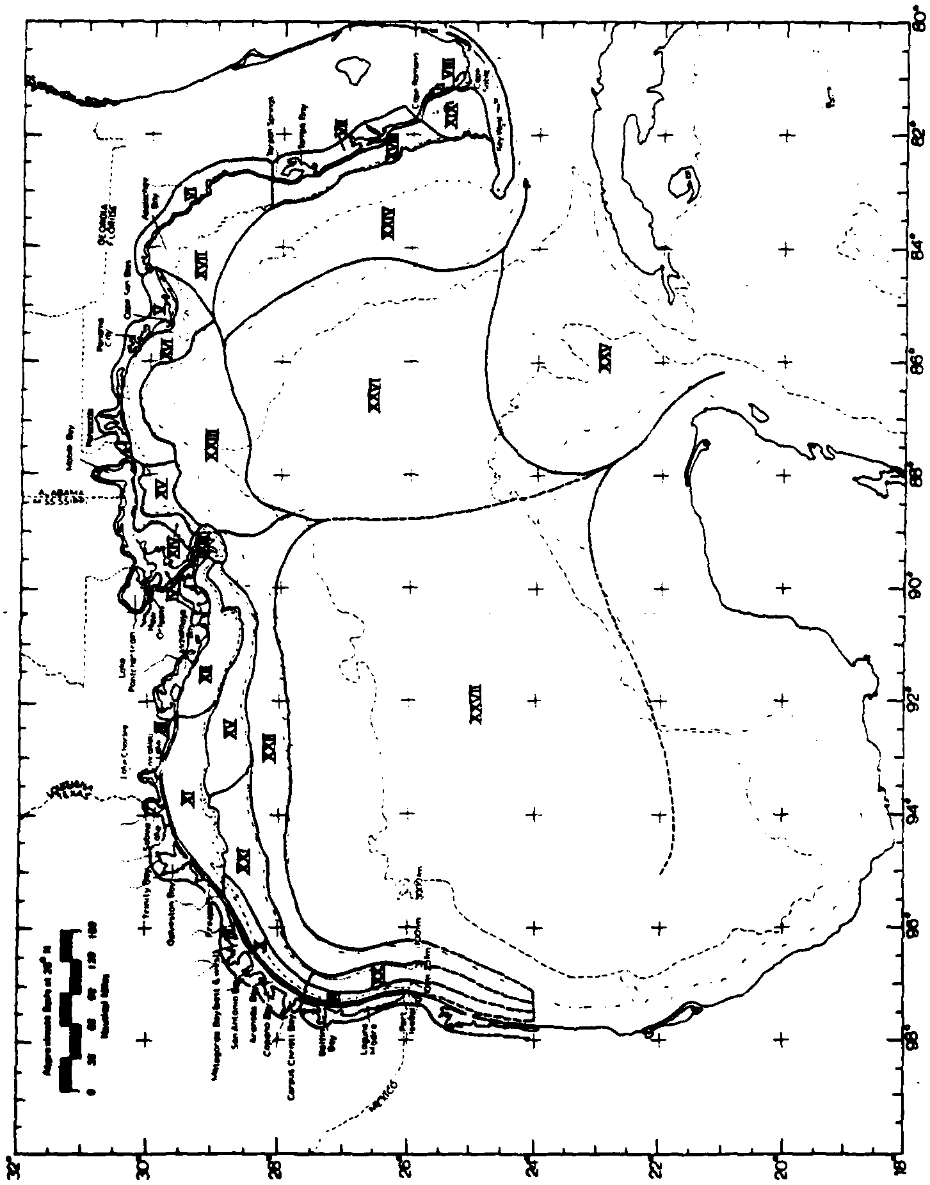


FIGURE A–1 DISSIMILAR HYDROBIOLOGICAL ZONES–GULF OF MEXICO

channels, and satellite industries. As Fisher et al. (1972) point out, the attributes that make the coastal region attractive for industrialization and development also make it particularly susceptible to a variety of environmental problems. Theoretically at least it is balanced between maintenance by natural physical, chemical, and biological processes, and effects of industry, urban concentration, and continuing coastal land development. Because the zone is buffeted by floods and hurricane impact damage, and modified by salinity changes within bays and estuaries, subsidence, vegetational stabilization of sediments, and other critical factors, Fisher et al. (1972) emphasize that man's impact can significantly affect the natural environmental balance.

Nevertheless, the necessity for man to use the coastal resource in sustaining his modern industrial society is obvious. Proper use will be realized when each of man's coastal activities is properly located, that is, located in such manner as to cause the least possible environmental damage.

We have apportioned the eight embayments of Texas into three hydrobiological zones. Zone I includes The Laguna Madre (upper and lower parts), Zone II encompasses Corpus Christi through Galveston Bays, and our portion of Zone III encloses Sabine Lake (Figure A-1).

B. GENERAL PHYSICAL CHARACTERISTICS

1. Hydrology

a. Physiography. – The embayments penetrate about 30 miles inside the outer coast to a line where the general slope of the coastal plain takes over (Lohse, 1955). Two main types of bays are recognizable (Emery et al., 1957): (1) lagoons, which extend parallel to the coast just inside a barrier island; and (2) estuaries, which receive a stream or river and extend inland at right angles to the coast. These brief descriptions are intended only to fit the embayments of Texas. As Shepard and Moore (1960) point out, no one of the Texas bays has an estuarine development as long as those characteristic of the east coast of the United States.

All of the embayments are relatively shallow with "deeps" ordinarily occurring at their mouths, where local tidal currents have scoured holes as deep as 30-40 feet. Inside these channels, there are no natural depths in excess of 13 feet in any of the Texas bays (Shepard and Moore, 1960). Generally the bay floors are flat, but exceptions occur where oyster reefs have formed ridges across or along the bays.

The annual rainfall along the coast of Texas ranges from about 24 inches near Brownsville to 56 inches at Sabine Lake (Figure A-2). Large as the southern totals appear, evapotranspiration exceeds rainfall by anywhere from 28 inches to 1 inch on a gradient from Brownsville to Matagorda (Figure A-3). At East Bay in the Matagorda complex precipitation and evaporation equal out, and from that point eastward rainfall gradually exceeds evaporation. These facts plus other weather factors result in the designation of four climatic belts that run normal to the

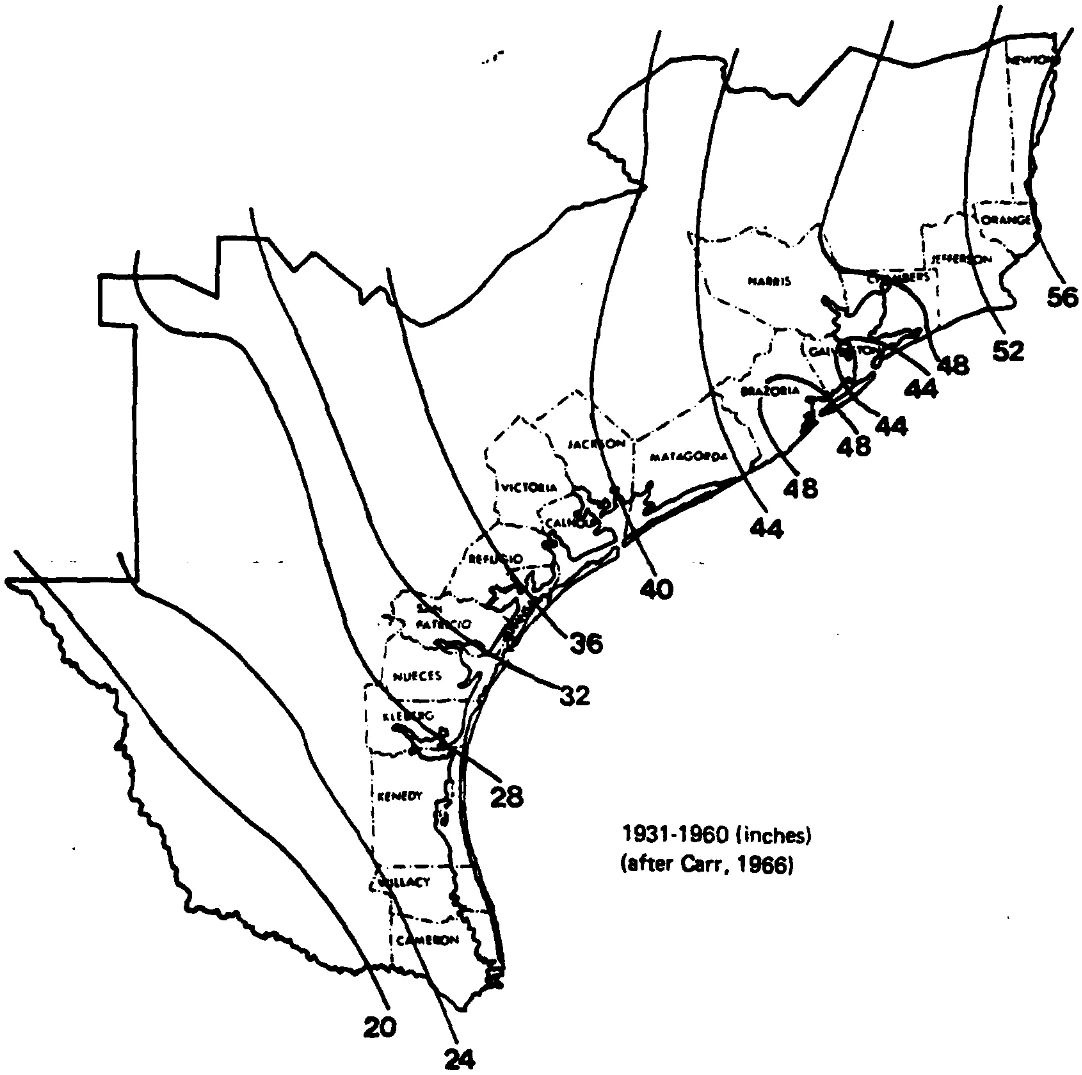


FIGURE A-2 ANNUAL RAINFALL, TEXAS COAST

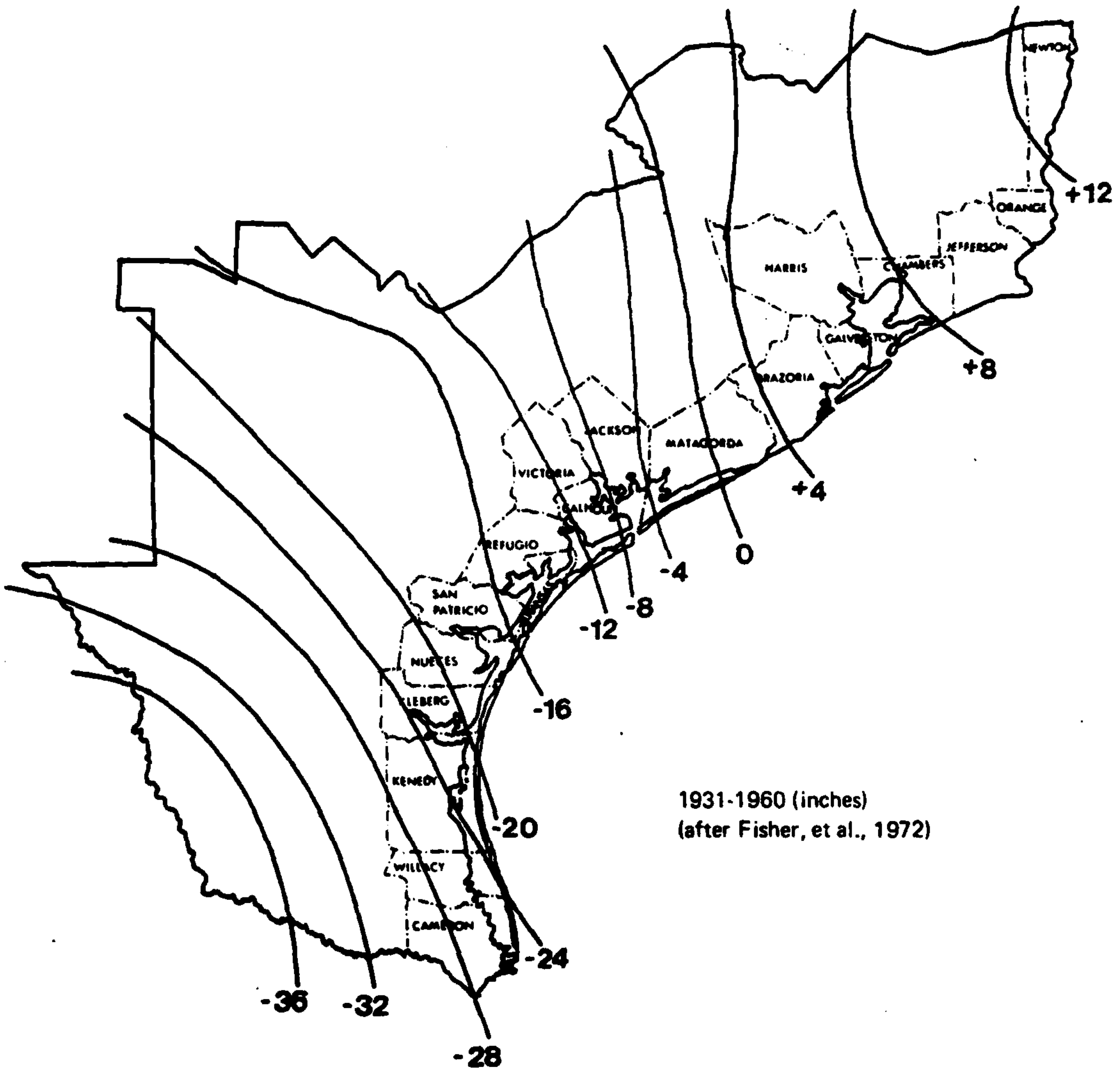


FIGURE A–3 ANNUAL RAINFALL MINUS EVAPOTRANSPIRATION, TEXAS COAST

coastline (Figure A-4). In Figure A-4 it is apparent that The Laguna Madre lies wholly in the semi-arid belt, whereas Sabine Lake occurs in the humid belt. Dividing lines between the other belts occur through Corpus Christi Bay, Matagorda Bay, and Galveston Bay (Figure A-4).

b. Salinity. – The waters of these lagoon-estuarine complexes frequently display a marked high-to-low salinity gradient from mouth to river delta. More interesting, however, is the remarkable reduction gradient in salinity from the metahaline (40-80°/oo) Laguna Madre, through a series of mesohaline (10-40°/oo) bays of the central Texas coast to the brackish Sabine Lake at the Texas-Louisiana border (Figure A-5).

c. Temperature. – Water temperatures have a seasonal range, based on monthly averages, from about 10 to 28°C (Figure A-5).

d. Tides. – Because most of the bays of the Texas coast have very restricted openings to the Gulf, their responses to tidal changes on the open coast are considerably dampened (Collier and Hedgpeth, 1950). The sea tides of the Texas coast are of the mixed type with one low and one high per 24-hour period of maximal range, between 2 and 3 feet, and two highs and two lows per 24-hour period with a minimum range of less than 0.5 foot. The estuarine tidal ranges are very small (tenths of feet) and are reached 1 to 5 hours later than the corresponding high for the sea tide, and lack much periodicity.

The significant tidal changes in the bays are those created by winds. This is especially true of hurricane winds, which may raise tidal levels many feet. For instance Tannehill (1945) cites examples of storm tides as high as 16 feet.

e. Currents. – There are several factors that account for the circulation of waters in the Texas bays. The rivers bring in freshwater which flows over the more saline bay waters and carries finely divided sediments out into bays. These outflowing currents usually run along the west sides of the bays and hence carry much of the clayey sediment along that side. The salty heavier water from the Gulf of Mexico, coming in via the inlets, moves under the freshwater along the bottom. It also moves up the east side of the bays. As a result the sandy sediments from the inlets tend to move up the east side of the bays.

As might be expected, winds are more important in determining circulation patterns in these bays than are the relatively small astronomic tides. The winds also have a very important effect on the currents coming in the inlets. Generally north winds created southeast currents flowing out of the passes, and south winds give rise to northwest currents flowing into the passes (Shepard and Moore, 1960).

f. Winds. – The wind rose shown in Figure A-4 indicates that the overriding winds along the Texas Coast come from the southeast with average monthly speeds of from 9.7 to 14.7 mph. These southeast winds normally predominate during the spring and summer months at velocities ranging on a daily basis from 5 to 35 mph.

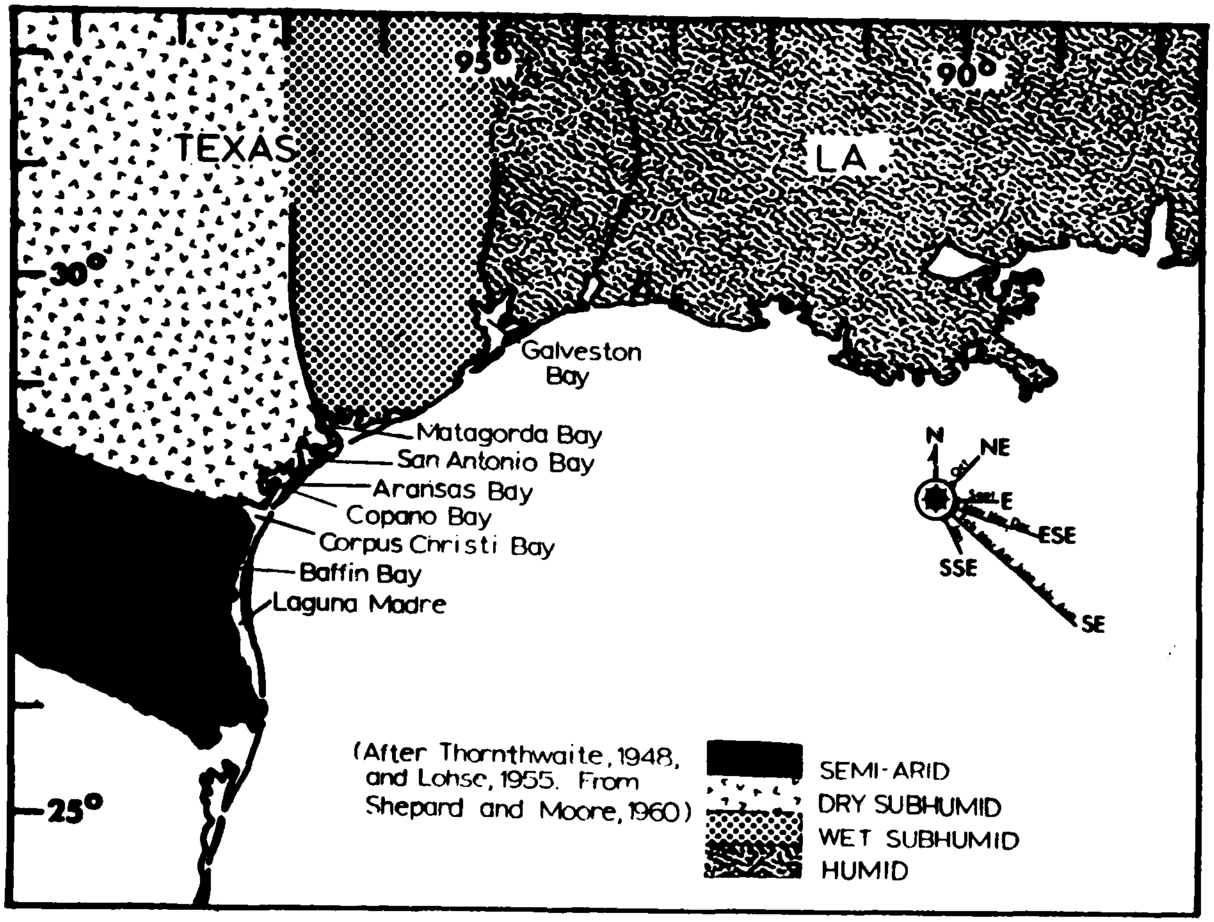


FIGURE A–4 CLIMATIC BELTS AND PREVAILING WINDS

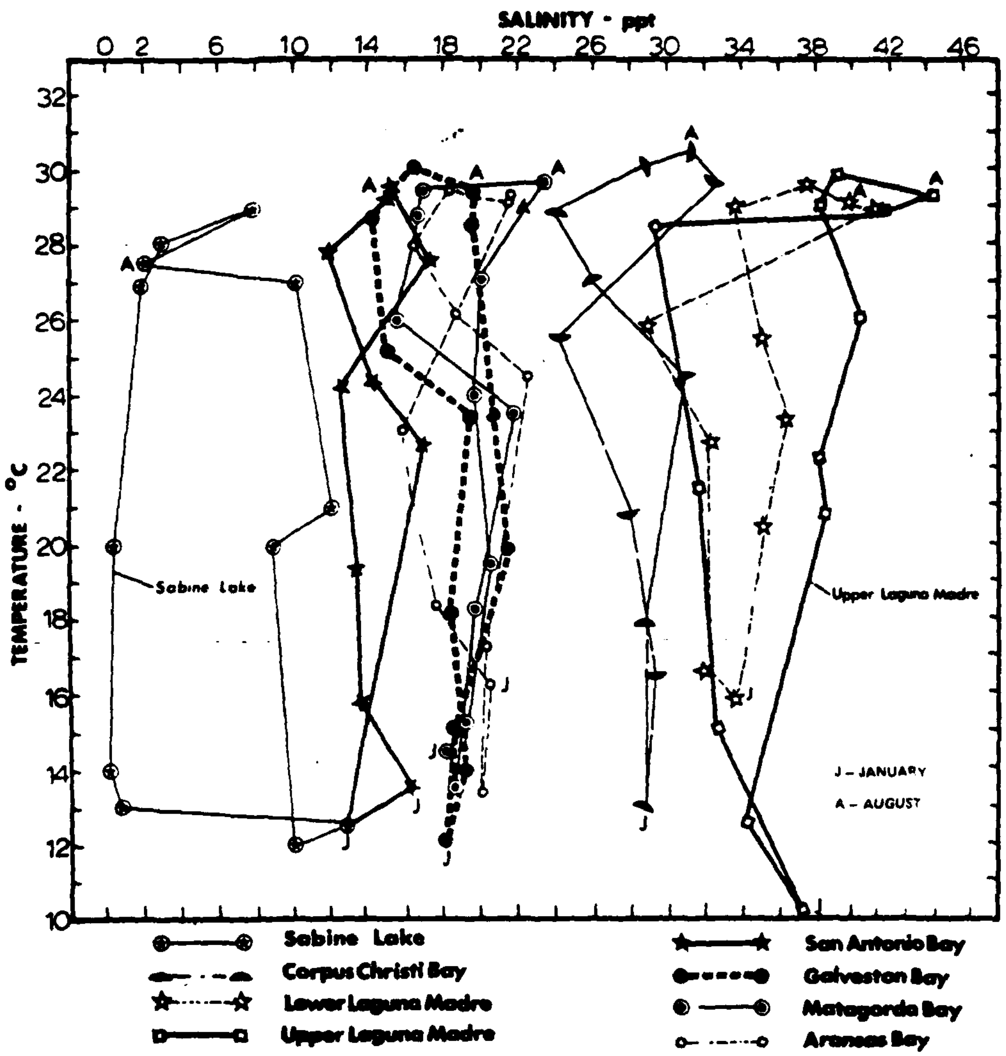


FIGURE A–5 TEMPERATURE-SALINITY HYDROCLIMOGRAPHS, TEXAS BAYS (compiled from Martinez, 1965, 1966, 1967, 1968 and Stevens, 1960)

During the winter, northerly winds occur at biweekly intervals with speeds ranging up to 70 mph. The alternation of wind direction and normal lunar tides moves the water back and forth over salt flats.

g. Storms. – Hurricanes are a relatively common occurrence on the Texas coast from June to October. Figure A-6 shows the number of times that hurricanes have occurred in eight coast-to-offshore sectors during the period from 1900 to 1956. This shows a clear frequency gradient that increases from Zone I to Zone III inshore and offshore as well.

2. Geology

As Hayes and Scott (1964) point out the estuaries and lagoons along the Texas coast are being filled with sediments that are transported by rivers and streams, by currents entering embayments through tidal passes, eroded from older deposits on the bay margins, washed across the barrier islands by storm surges, and blown in from back-island dune fields. Hurricane winds have the most important effects on major sediment transport in the Texas bays. During passage of a hurricane in the vicinity of a pass, the water rises several feet along the outer coast and results in pouring great quantities of water through normal inlets as well as through previously closed ones. This action carries sediments into the bays and builds washover fans from the barrier islands, thus decreasing bay size (Shepard and Moore, 1960). Obviously the rate of filling can be expected to reduce from north to south on the Texas coast, as does the amount of runoff. But the degree of this reduction gradient is moderated by other factors. Alluvial clays, silts, and sands do accumulate more rapidly in the humid parts of the Texas coast, but in the arid areas to the south, authigenic materials, such as carbonate mud, oolites, and shell accumulations fill the gap left by scarcity of alluvial sediments (Hayes and Scott, 1964).

The bays behind the central Texas coast barriers are receiving sediments that are quite distinctive both from the barrier island sediments and from those of the continental shelf outside (Curray, 1960). These bay sediments differ from barrier sediments in having a much lower content of sand except along the bay margin. The most typical bay sediments are silty clays with little or no stratification (Shepard and Moore, 1960). The admixture of sand sediments washed in through the inlets to the lower shallow bays with clayey sediments brought down the bays from the rivers produces a clayey sand or sandy clay that is rare in shelf deposits.

3. Chemistry

Determination of the amount of dissolved oxygen in bay water, expressed in milliliters per liter (ml/l) or percentage of saturation can be used in determining the degree of pollution of a bay. Oxygen concentrations drop when high organic loads coming from wastes are attacked by bacteria with a consequent increase in oxygen demand. The oxygen levels of the shallow bays are increased by wind turbulence, which increases the surface area of water and facilitates mixing, and by rainfall in that freshwater floats on top and dissolves more oxygen than sea water.

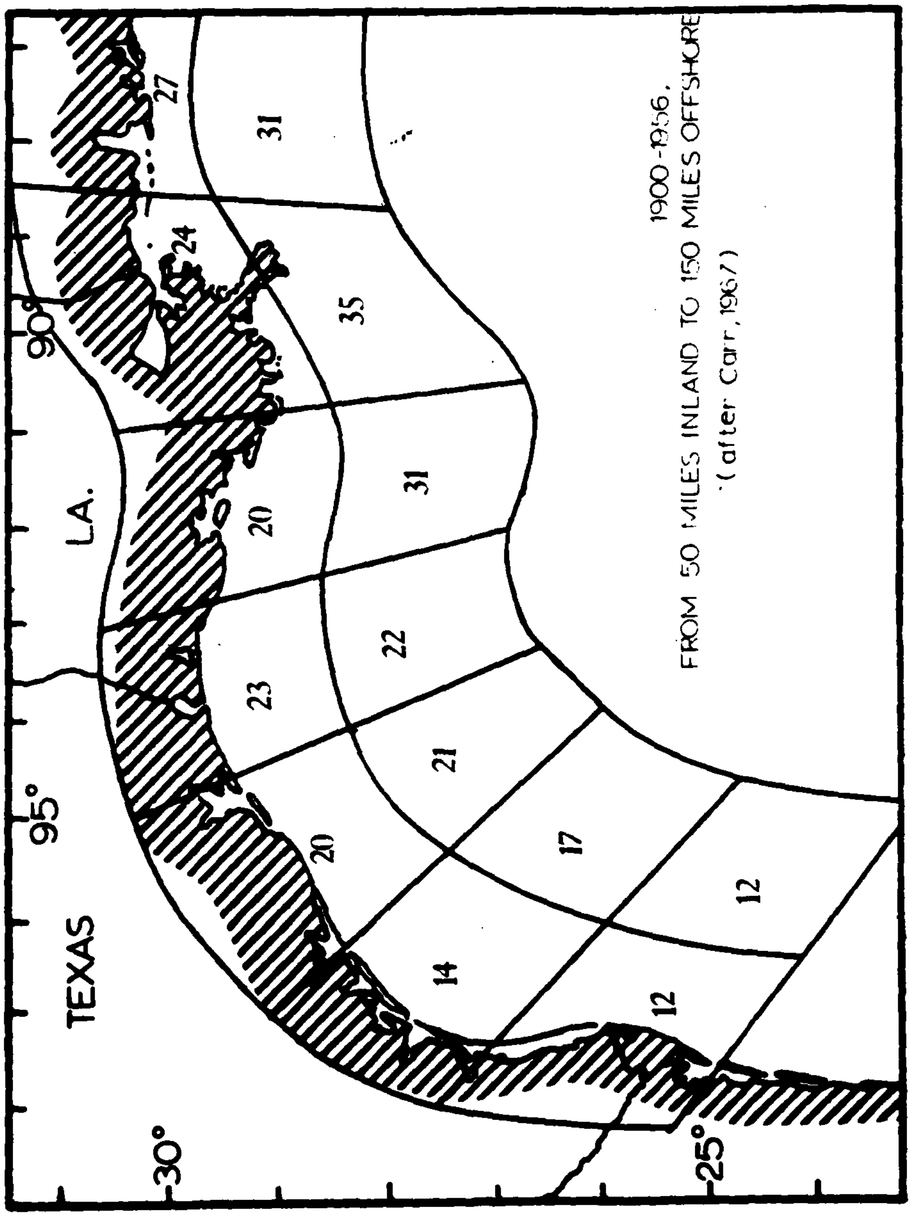


FIGURE A-6 HURRICANE OCCURRENCE

Photosynthesis also generates oxygen, but the respiratory need for oxygen by the plants often balances the production.

The pH value of sea water is one marker of the biological quality of the water. Organisms in the water column are placed in jeopardy when the volume of acid changing effluent of any kind is sufficient to swamp the buffering capacity of sea water. As a general rule, high salinities tend to be associated with high pH values.

Quite frequently, but certainly not always, available phosphate in the water may be the most critical limiting nutrient in embayments. Thus, any foreign matter dumped into an estuary that substantially removes inorganic phosphate by complexing can reduce primary production of organics by phytoplankters.

Silica, also, is an important nutrient especially as a structural compound in the frustules of diatoms, which can be important links in the food webs of the estuary.

C. MAN'S ACTIVITIES

1. Residential, Business, and Industrial Developments

a. General Information. – The Texas Coastal Zone has the greatest concentration of chemical plants in the United States. They produce on an annual basis more than 40% of every basic petrochemical, 80% of the synthetic rubber, and 10% of the sulphuric acid in the United States. During 1960-69, 118 new chemical and allied materials plants located in the Houston area, and 272 plants expanded. The principal chemical products produced in Texas include the following: ethylene (15 billion lbs/yr); propylene (7.5 billion lbs/yr); butadiene (1.3 million gals/yr); toluene (16 plants on coast); xylene (1.6 billion lbs/yr); chemical fertilizers (more that 5 million tons/yr); sulphuric acid (8000 tons daily) (Texas Almanac, 1972).

b. Deep-Water Ports. – Of the 15 deep-water ports along the 475 miles of Texas coastline (Figure A-7), only three are located in Zone I (Brownsville, Port Isabel, and Port Mansfield); eight are located in Zone II (Houston, Port Aransas-Corpus Christi, Texas City, Freeport, Port Lavaca, Galveston, Chocolate Bayou, Long Mott); and four are found in the Texas part of Zone III (Beaumont, Port Arthur, Orange and Sabine Pass Harbor). The physical characteristics of Texas' major ports are given in Table A-1.

Only 5 of the 15 deep-water ports may be considered as major ports, i.e., handling over 10 million tons of cargo per year (Table A-2). These are Houston, Port Aransas-Corpus Christi, and Texas City in Zone II, and Beaumont and Port Arthur in Zone III. Together these handled 153 million tons of cargo in 1969, on the order of 86% of all major cargoes handled by Texas deep-water ports. If, however, we were to feature the harbors that handle the major poundage of shrimps, a different set of leaders emerge. For instance, Miloy and Copp (1970) show that in 1968 the leader in regard to shrimp landings was Port Isabel-Brownsville of Zone I with 18.9 million pounds, followed by Aransas Pass-Corpus Christi of Zone II with 13.6 million

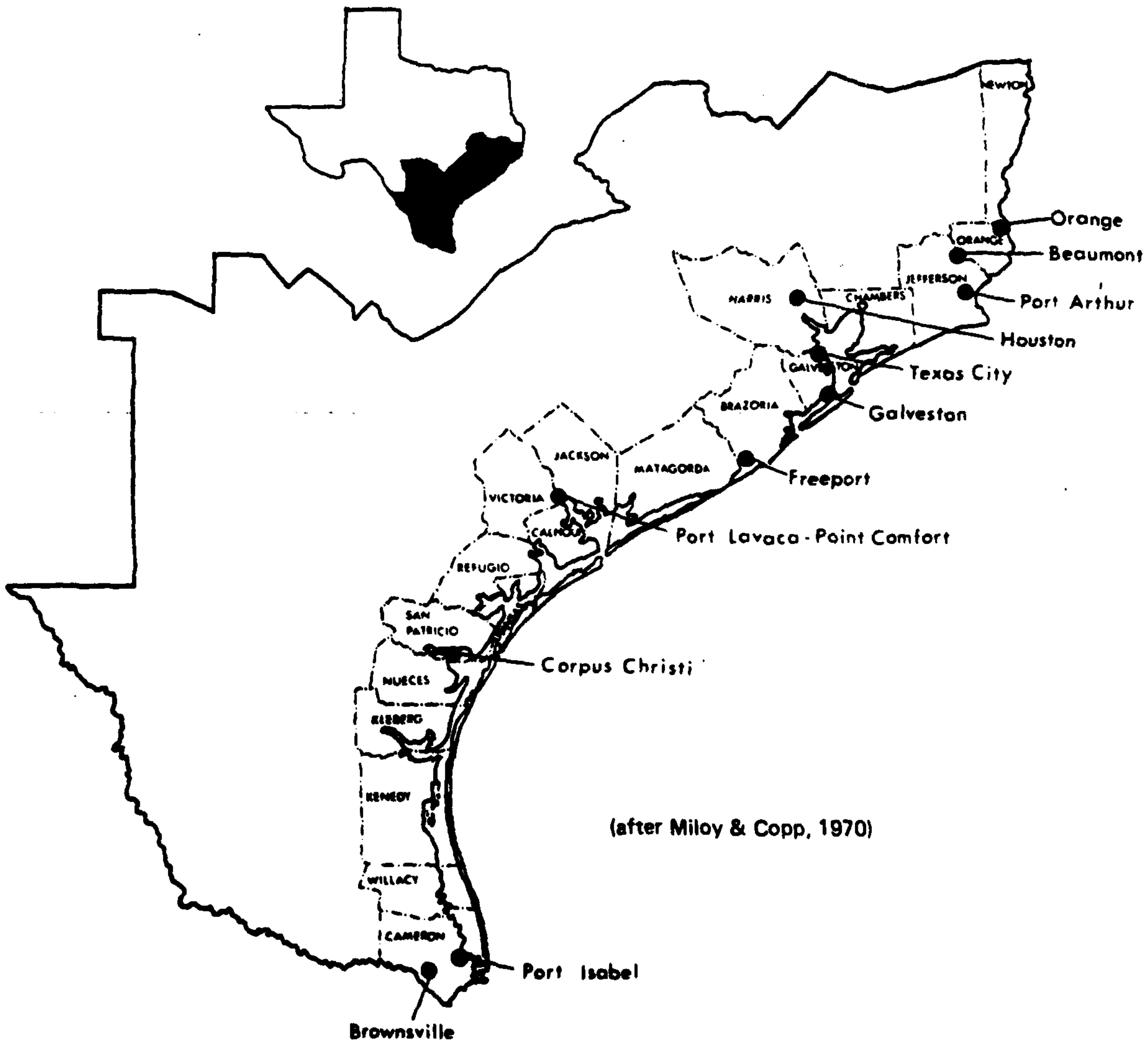


FIGURE A-7 LOCATION OF MAJOR PORTS IN TEXAS

TABLE A-1

GENERAL CHARACTERISTICS OF MAJOR PORTS ON THE TEXAS GULF COAST

Port	Size (Sq. Miles)	Governing Body (Commissioners)	Size of Staff	ACCOMMODATIONS Transit Sheds (Sq. Feet)	Open Docks (Sq. Feet)	Bunkers Available	Ship Repairs
Beaumont	149.90	6	50	349,000	235,000	Yes	No
Brownsville	315.10	N.A.	7	100,000	N.A.	Yes	Yes
Corpus Christi	838.00	3	10	508,000	N.A.	Yes	Yes
Freeport	1,124.00	5	13	156,720	N.A.	Yes	Yes
Galveston	94.11	7	N.A.	4,484,952	979,100	Yes	Yes
Houston	1,747.00	5	26	1,616,004 (enclosed) 1,916,621 (open area)	N.A.	Yes	Yes
Orange	356.00	5	N.A.	285,350	41,400	Yes	Yes
Port Arthur	58.00	5	N.A.	108,000	360,000	Yes	Yes
Port Isabel	317.50	3	4	52,000	50,000	Yes	No
Texas City	960.00	Private	100	N.A.	40,000	Yes	Yes
Port Lavaca-Port Comfort	127.00	6	12	N.A.	15,000	Yes	No

N.A.–Not Available
Source: Respective port authorities.

Table A-1. (After Miloy and Blake, 1970)

TABLE A-2

MAJOR DEEP-WATER PORTS OF TEXAS BY HYDROBIOLOGICAL ZONES

Port	Short Tons Handled (Millions) 1968	1969
Zone I		
Brownsville	4.84	4.91
Port Isabel	0.33	0.36
Port Mansfield	-----	-----
Zone II		
Port Aransas — Corpus Christi	28.40	29.85
Long Mott (San Antonio Bay)	-----	-----
Port Lavaca	5.03	5.21
Freeport	4.63	5.86
Galveston	2.82	2.75
Chocolate Bayou (Galveston East Bay)		2.38
Houston	57.81	55.96
Texas City	16.71	16.56
Zone III		
Port Arthur	22.63	23.54
Beaumont	30.79	27.04
Orange	1.54	1.59
Sabine Pass Harbor	-----	-----
Totals	175.53	177.90

(tonnages for 1968 after Miloy & Copp, 1970; for 1969 after Texas Almanac, 1972).

pounds, Freeport (Zone II) with 9.2 million pounds, Galveston (Zone II) with 4.7 million pounds, Port Lavaca (Zone II) with 2.8 million pounds. Matagorda (Zone II) 1.9 million pounds, and Zone III Sabine Pass-Port Arthur with 1.3 million pounds (Figure A-8).

c. The Gulf Intracoastal Waterway. – At this point something must be said about the Intracoastal waterway that runs in Texas alone some 423 miles from Orange to Brownsville. The 1110-mile Gulf Intracoastal Waterway is a land-protected course beginning at Carrabelle, Florida, running across Alabama, Mississippi, and Louisiana through Texas.

The development of the Gulf Intracoastal Waterway has been in segments; each segment built to fill the needs of a specific local area. The first survey was authorized by Congress in 1873 to select a route from an inland waterway to interconnect the Mississippi River to the Rio Grande. Actually the first development was the digging in 1892 of a channel in Galveston Bay some three and one-half feet deep by 200 feet wide. The last link, across the Laguna Madre, was completed in 1949. Over 60 million tons of cargo are shipped over the waterway each year. The greatest share of this volume of tonnage consists of petroleum products that are shipped from Texas and Louisiana refineries throughout the nation.

d. Oil Refineries. – Zone I has no significant refinery capacity. Three sites (Figure A-9) in Zone II accommodate the largest number of oil refineries with the largest daily capacity in the Texas Coastal Zone. These are in order of importance Texas City-Houston (9 refineries, capacity of 1,435,000 barrels/day): Corpus Christi (4 refineries, capacity of 308,000 barrels/day); and Matagorda (1 refinery, capacity of 85,000 barrels/day). Zone III is second in refinery capacity because of the great importance of Port Arthur, which has 6 refineries with a capacity of 1,312,000 barrels/day. It is estimated by Bragg and Bradley (1972) that the above total coastal capacity of 3.14 million barrels per day will rise to 3.94 million barrels in 1975, 5.22 million in 1980, and 6.50 million barrels in 1985. Actual daily runs in barrels will probably be below the above capacity figures by 0.5 (1975); 0.7 (1980), and 0.8 (1985) million barrels. The dollar value per barrel of refined crude is expected to rise from $4.50 in 1975 to about $5.50 in 1985. It is interesting to note the major types of cargoes handled by various ports in Texas in 1967 (Figure A-9a). Here we see that over three quarters of the cargoes handled are liquid in all Texas major ports except Orange, Houston, Corpus Christi and Galveston.

2. Fisheries

In presenting the general picture of the relative values of the bays of Texas to the fisheries economy, it is essential that a distinction is drawn between the finfish and shellfish actually captured in the various bays and the pounds of finfish and shellfish landed at ports in one or another of these bays.

Table A-3 looks at the dollar contribution of each Texas Bay of importance to the total value of fishery in the state for the years 1967 and 1968, and then this is

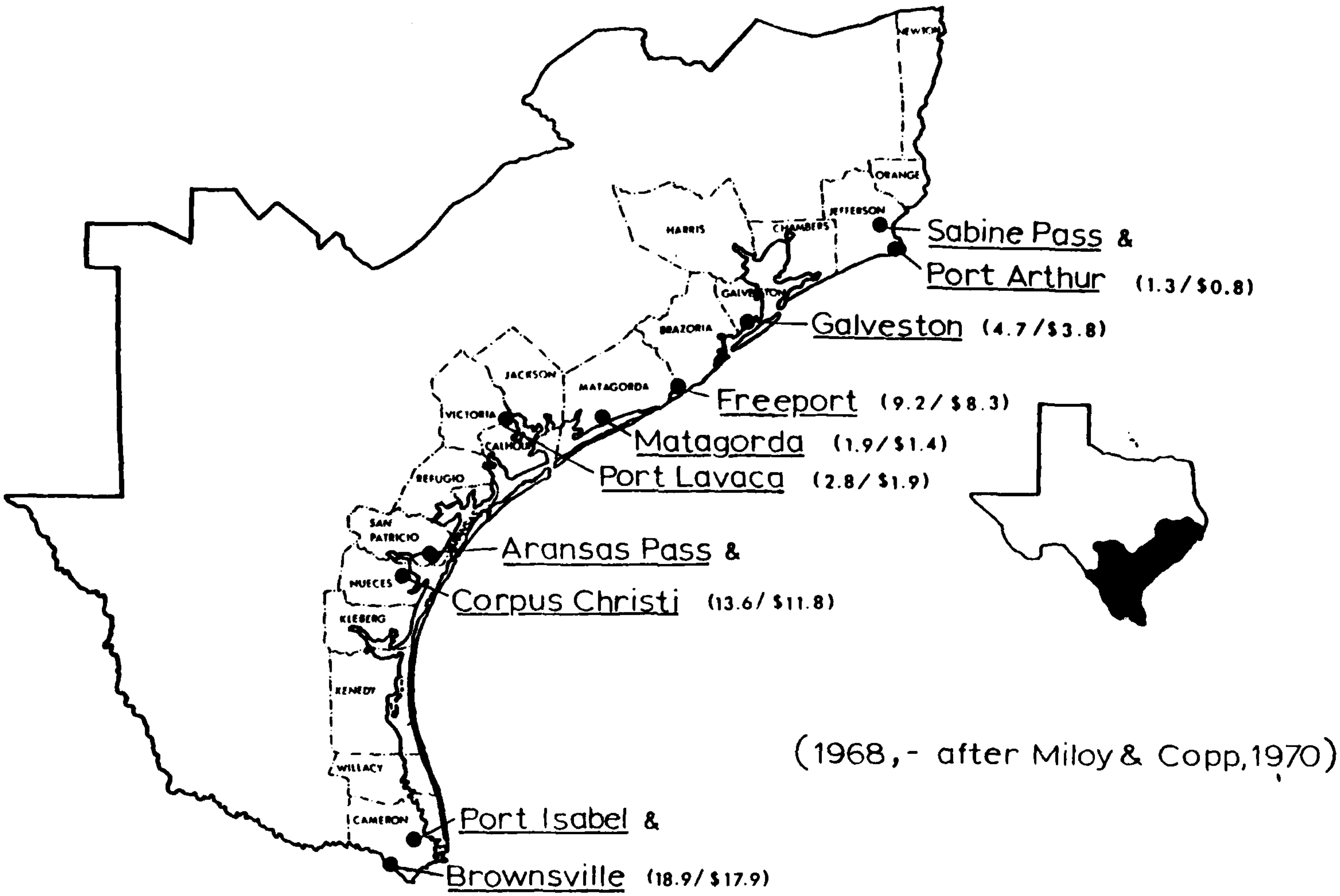


FIGURE A–8 POUNDS AND VALUE OF SHRIMP LANDED AT SELECTED TEXAS PORTS

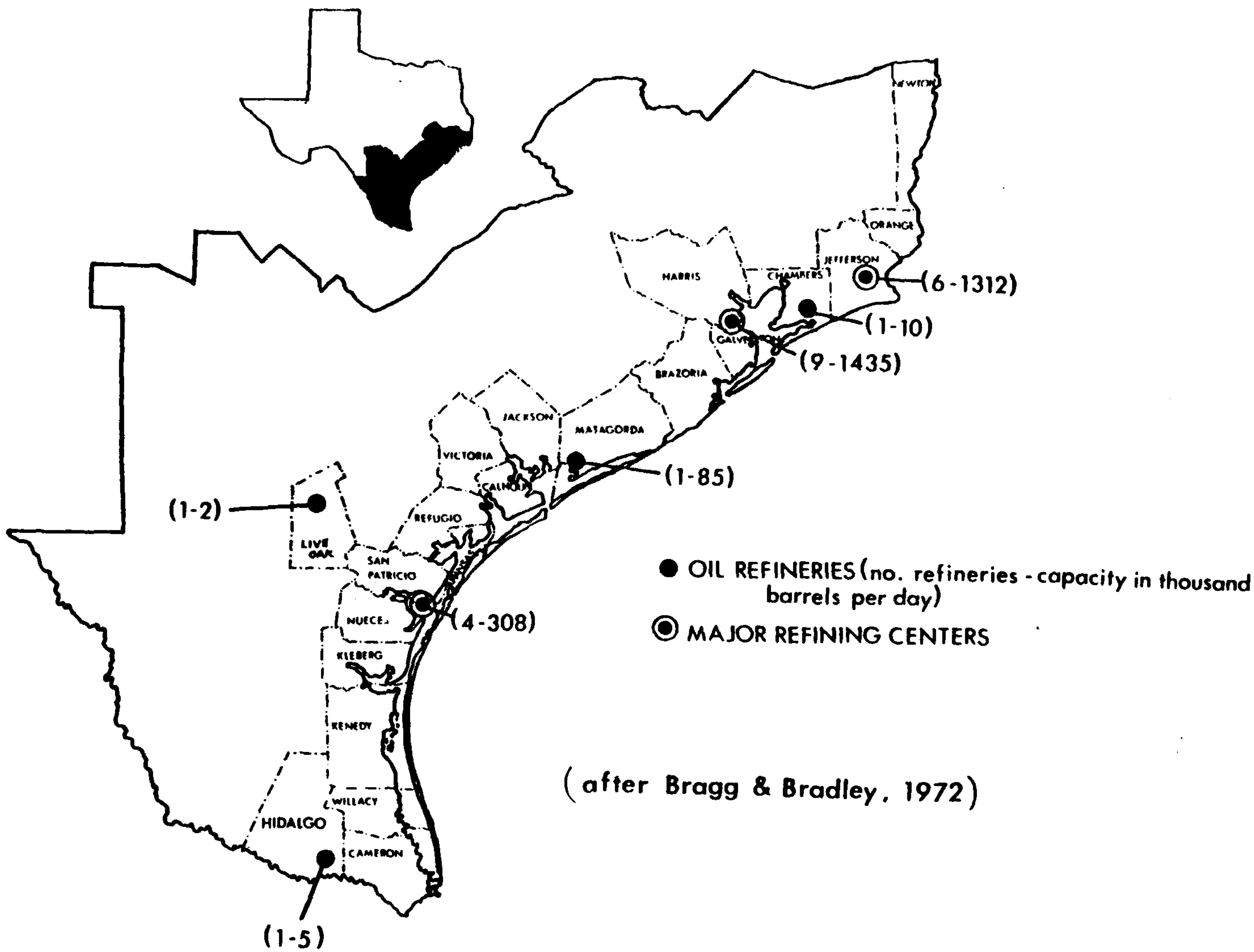
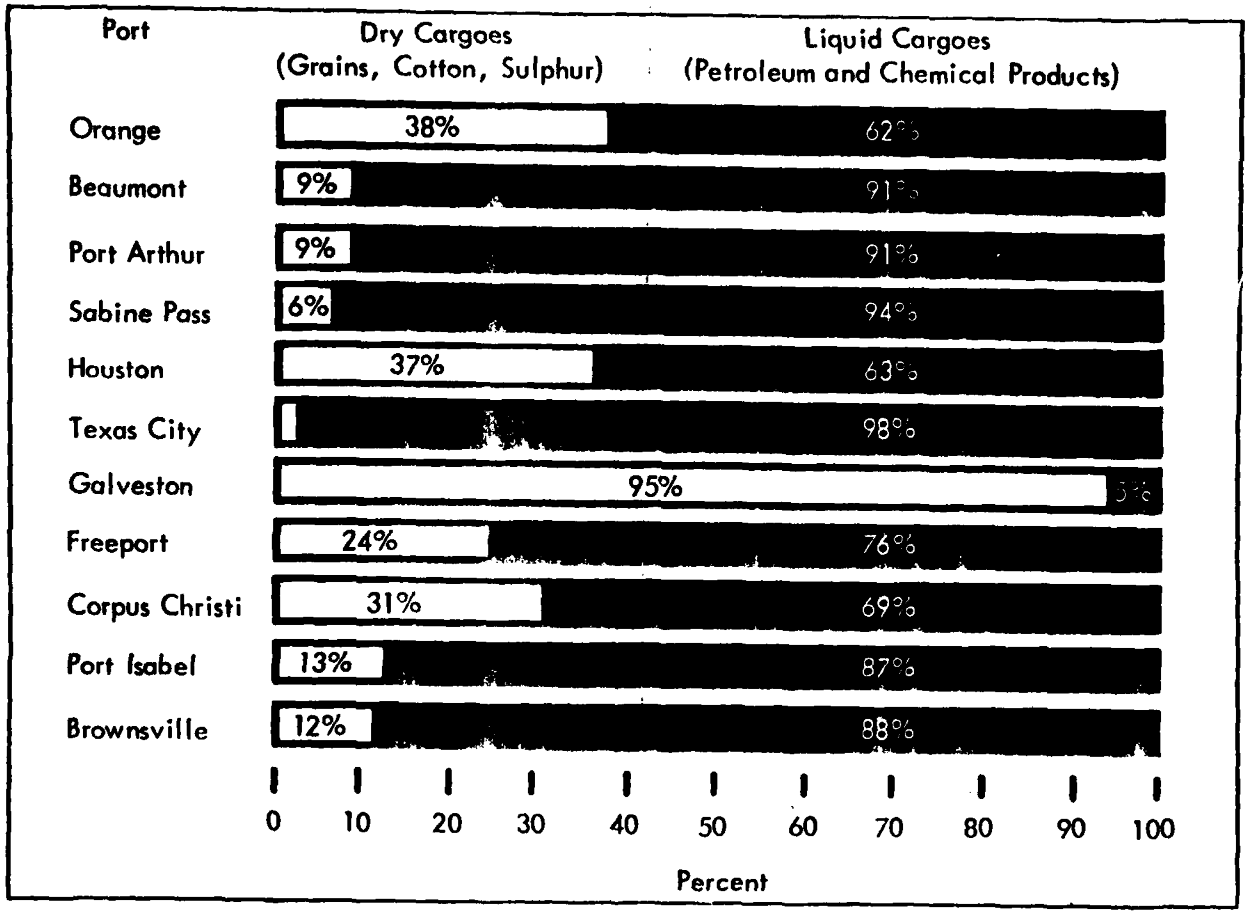


FIGURE A-9 TEXAS GULF COAST REFINERY CENTERS



(1967, from Miloy and Blake, 1970)

FIGURE A-9a TYPES OF CARGO HANDLED BY MAJOR TEXAS PORTS

TABLE A–3

VALUE* OF TEXAS CATCH OF FINFISH AND SHELLFISH
DURING 1967 AND 1968

Bay	*Dollar values (to the fishermen) Finfish 1967	Finfish 1968	Shellfish 1967	Shellfish 1968
Zone I				
Baffin Bay and Upper Laguna	$ 178,000	$ 151,000	$	$ 46,000
Lower Laguna Madre	160,000	237,000	13,000	13,000
Zone II				
Corpus Christi-Nueces	43,000	21,000	160,000	229,000
Aransas and Copano	58,000	92,000	159,000	641,000
San Antonio, etc.	61,000	37,000	480,000	485,000
Matagorda, Lavaca, etc.	63,000	96,000	701,000	1,046,000
Galveston-Trinity	116,000	66,000	1,963,000	2,573,000
Zone III				
Sabine	8,000	12,000	72,000	98,000
Bay's Total	$ 687,000	$ 712,000	$ 3,548,000	$ 5,131,000
Gulf of Mexico Total	$ 847,900	$1,195,000	$44,613,000	$42,525,000
Grand Totals	$1,534,900	$1,907,000	$48,161,000	$47,656,000

Note that after Bay Total the catch for the Gulf of Mexico outside the bays is given (after Miloy and Copp, 1970).

compared with the catch in the Gulf of Mexico outside the bays. It is quite obvious (1) that the bays of Zone I produce the largest dollar value of finfish, but the smallest for shellfish, (2) that the bays of Zone II produce far more shellfish than the others, and (3) that the Gulf of Mexico exceeds the embayments in dollar value of product, almost exclusively because of its rich harvest of shrimps.

In light of the above it is interesting to note the principal commercial fishes of Texas and the number of pounds and dollar value (to the fishermen) of the 1968 catch (after Miloy and Copp, 1970).

	Pounds	Dollars
1. Menhaden	51,073,400	674,242
2. Spotted Sea Trout	1,871,300	419,150
3. Red Snapper	1,127,500	366,843
4. Redfish	924,900	215,469
5. Black drum	677,400	87,054
6. Flounder	336,200	75,438

Of the above six leading species of fish numbers 2, 4, and 5 are particularly common in some of the bays. The others are taken in the Gulf.

About 4.7 million pounds of oyster meats, valued at $2 million at dockside were landed in Texas during 1970. Where they were taken in percentages are shown below (after Crance, 1971).

Galveston and Trinity Bays	86.4
Matagorda-Lavaca Bays	8.3
San Antonio	3.3
Aransas and Copano Bays	1.9
Lower Laguna Madre	0.1
	100.0

In 1970 over 5.5 million pounds of blue crabs (*Callinectes sapidus*) were taken from Texas bays, as shown below. The dollar value at the dock, according to Crance (1971) was $508,800.

Although the blue crab has a much wider environmental distribution than the oyster, primarily because of its broader tolerance for higher salinities, it is caught in largest numbers in the Galveston Bay complex.

Blue Crab Capture Locations	Percent of Total Catch
Gulf of Mexico	0.4
Zone I	
Sabine Lake	12.7
Zone II	
Galveston and Trinity Bays	36.5
Matagorda-Lavaca Bays	14.1
San Antonio Bay	17.0
Aransas and Copano Bays	13.5
Corpus Christi-Nueces Bays	1.3
Zone III	
Baffin Bay and Upper Laguna	4.5
	100.0%

Shrimp. – Although shrimp is the most valuable fishery in Texas, only 11.8% of the catch in 1970 was taken from embayments. The remaining 88.2 percent was taken in the open Gulf. These figures do not reflect, however, the absolute necessity that young shrimp spend an essential part of their life cycle on the nursery grounds within the bays. The bays in which the 11.8% of the Texas shrimp catch were taken are shown below:

Zone I	
Baffin Bay and Upper Laguna Madre	0.1%
Zone II	
Galveston and Trinity Bays	6.2
Matagorda-Lavaca Bays	2.2
San Antonio Bay	1.5
Aransas and Copano Bay	1.3
Corpus Christi-Nueces Bays	0.4
Zone III	
Sabine Lake	0.1
	11.8%

It should be pointed out that even though this percentage is small, still it was worth 4.8 million dollars dockside, which exceeds the value of the oyster, blue crab, and finfish catch from Texas embayments. Moreover, all of the above figures dealing with percentage of catch point to the value of Galveston-Trinity Bays to the fisheries of Texas. Efforts should be continued to clean up this estuarine complex.

3. Recreation and Leisure

There are 16 important state parks, state recreation areas, and national preserves on the embayments of Texas, including Sabine Wildlife preserve on Sabine Lake (actually in Louisiana) (Figure A-10). Four of these are in Zone I, 11 are in Zone II, and only one, mentioned above, is in the Sabine part of Zone III. Actually the most significant concentration of these recreational, educational, and aesthetic facilities are clumped around Aransas-Copano Bays in Zone II.

D. ZONE I – THE LAGUNA MADRE LAGOON-BAY COMPLEX

1. Summary

Zone I and the Laguna Madre of Texas that it encompasses was set apart because its bay-lagoon complex is the only one in Texas that is not truly an estuary, the only one that is normally hypersaline throughout, and the only one that is situated in the semiarid climatic zone.

The Laguna Madre of Texas encompasses shallow coastal lagoons, bays, and salt flats that are separated from the Gulf of Mexico by that major link in the chain of barrier islands extending along the Texas coast called Padre Island. The complex stretches from near Port Isabel on the south to the Corpus Christi Causeway on the north and covers slightly more than 460,000 acres (Figure A-11). The main lagoons, which are referred to as the Lower Laguna Madre (southern) and Upper Laguna Madre (northern), are separated by the extensive, dry, and nearly barren Saltillo Flats, almost midway along the north-south line of the complex. Baffin Bay extends westward from the inner margin of Upper Laguna Madre and receives Alazan Bay on its northern perimeter. Even though the complex is bisected throughout its entire length by the Intracoastal Waterway, the Laguna is so shallow (generally less than four feet) and its connections with the Gulf so few and of such uncertain tenure that no additional part of it (than Port Isabel) is likely to become a major port of commerce in this century.

Located in the semiarid climatic zone (Thornthwaite, 1948), where annual evaporation exceeds average annual rainfall by several inches, this hypersaline Laguna system tends to stand apart from all other embayments on the Texas coast (Figure A-4). Maximum periods of rainfall are concentrated during late spring and in September when tropical storm activity reaches a peak (Hayes and Scott, 1969). Located in the most arid part of the Texas coast where air temperatures range from an average of 15°C in January to 29°C in July, Laguna salinities can and do vary from nearly 0 to 79°/oo, with an average well above that of the adjacent Gulf of Mexico. Extremes of water temperature are also characteristic of the complex. The two important wind regimes of the region are the prevailing southeasterlies, which peak out in spring and the much stronger but sporadic northerlies which result from passage of winter "cold fronts." These winds are the principal factors controlling tidal changes in the Laguna, since astronomical tides here are negligible and only 1.5 feet or so in the adjacent Gulf. Most of the supraoceanic conditions, particularly

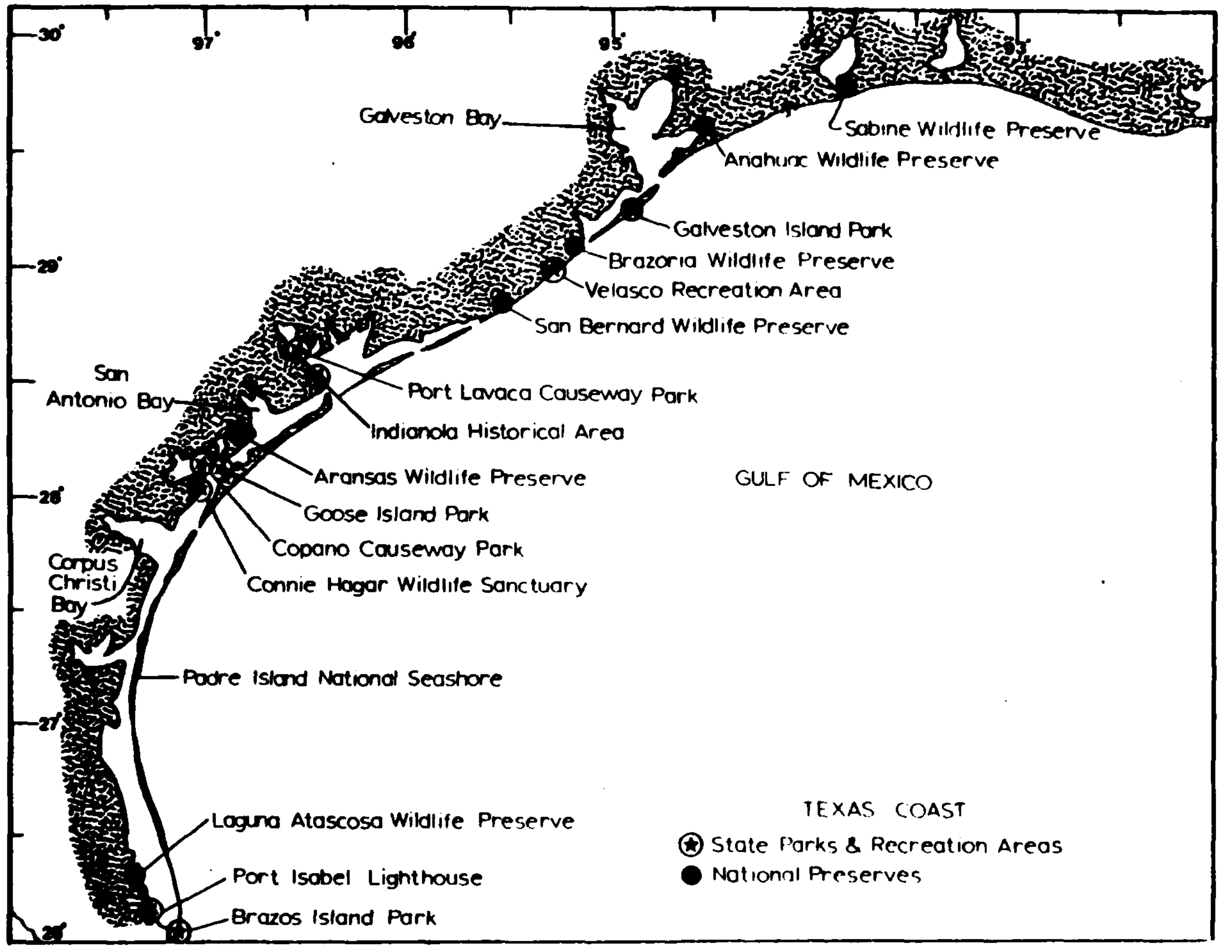
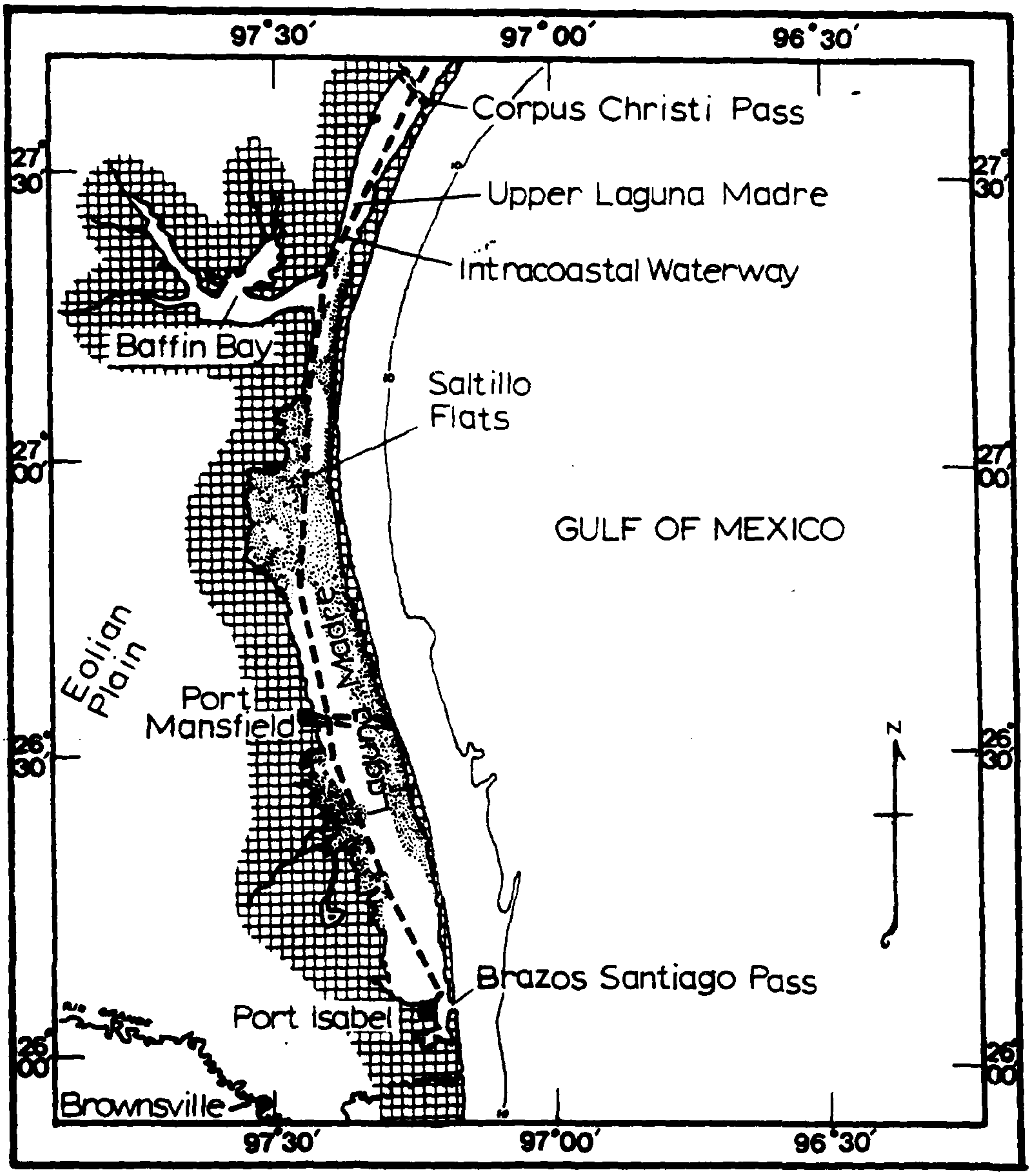


FIGURE A–10 STATE PARKS AND NATIONAL PRESERVES OF COASTAL TEXAS



(after Hedgpeth, 1967; and Rusnak, 1960)

FIGURE A–11 THE LAGUNA MADRE AND THE INTRACOASTAL WATERWAY OF TEXAS

hypersalinity and large extremes of temperature, result from limited inflow of river and Gulf waters, shallow depths, persistent winds, and high insolation with resultant high rates of evaporation.

The Upper Laguna and barrier flats of the southern Laguna consist mainly of sands deposited by washover storm waves and by wind action from Padre Island (Rusnak, 1960). In contrast to the oyster reefs that form the dominant nonclastic sediments in the subhumid, low salinity bays to the north, Rusnak (1960) reports the nonclastics in Laguna Madre are principally accumulations of disarticulated shells of such other bivalves as *Mulinia* and *Anomalocarida*.

The Laguna Madre has a unique development of biotic communities. In spite of its seemingly harsh temperature and salinity extremes, Miloy and Copp (1970) report that the dollar value of the finfish catch in Laguna Madre exceeds that of all other Texas bays combined. They point out, however, that its dollar contribution to the commercial shell fishery is less than 10 percent of the total garnered by all Texas bays. This poor showing results from the absence of oysters, which do not thrive in high salinities, and the scarcity in commercial terms of shrimps and blue crabs, especially in the high salinity portions.

This entire region can be characterized as one of low population density, scattered industrial development, and relatively low port transfer tonnage. On the other hand, the Laguna Madre, and particularly Padre Island, must be considered an important and growing center of tourism and recreational assets. Thus, some 80 miles of the barrier island was set aside in 1968 as the Padre Island National Seashore, and the inner part of the lower Laguna is the site of the Laguna Atascosa National Wildlife Refuge (Figure A-10).

Some attributes of Zone I appear at first glance to make it attractive as a site for installation of a deep-water terminal for handling petroleum and related products. Among these are its distance from major population centers with very low investments in such human resources as shore homes, port facilities, marina developments, and low investment in pleasure craft berthed in much of the area. Obviously some of these could be considered also as reasons why Zone I would make a poor site or even is a poor area as a receiving station for an off-coast terminal.

There appear to us to be overriding reasons why Laguna Madre *per se* should not be selected as a prime site for development of a port or a terminal. These are (1) its potentially greater contribution to recreational pursuits, (2) its present considerable contribution to the finfishery of Texas, (3) its shallowness and separation from the Gulf by the shifting sands of an arid barrier island, and (4) the present lack of operational refinery developments and of heavy-goods transportation facilities. Numbers 1 and 2 above are features of high vulnerability to oil spills that would wash ashore, primarily for aesthetic as well as public health reasons; numbers 3 and 4 suggest that so much modification of the environment would have to be wrought upon the region to make a suitable port site and to maintain it as to make the project economically unsound.

Moreover, it may as well be said here as elsewhere, it might well become a standard of public policy that future manipulations of coastal areas should be minimized in locales that appear to display some chance of remaining relatively free of man's more damaging activities, and should be concentrated around loci where degrading influences are in high concentration but where, at the same time, public concern is keen and strong and ameliorating countermeasures are being studied and put into effect.

2. Physical Characteristics

a. Hydrology

(1) Physiographic. – The Laguna Madre of Texas is a series of coastal lagoons, consisting of a long, narrow outer lagoon separated from the Gulf of Mexico by Padre Island, and divided into northern and southern parts by extensive, barren flats, and an inner tributary Baffin Bay, extending westward like an elbow from the lower part of the main Laguna (Hedgpeth, 1967). The area of the lagoons and bays is 390,000 acres and of the total system including Saltillo Flats, is about 460,000 acres. The latter, which divides the Laguna into two major parts, is composed of layered sand and mud. It is thought to have formed within the last century (Ladd, 1951). At times this area can be covered by a few inches of water during extreme tides caused by high winds. After the construction of the Intracoastal Waterway, the two parts of the Laguna proper have been connected by a viable channel. Apparently, however, very little salinity exchange occurs through the channel, which is 125 feet wide and 12 feet deep, except during winter when highly saline water is moved into Lower Laguna Madre by the action of strong north winds (up to 70 mph).

The fact that the Laguna Madre differs from other Texas Bays is attributed to the following two conditions by Shepard and Moore (1960), viz., (1) that it is fed (and only sporadically) by small intermittent streams, and (2) that it has 100 miles of barrier island (Padre) that pretty much prevents direct access of Gulf Waters except at the two ends. Other factors will be emphasized later.

The entire Laguna Madre system is extremely shallow (Table A-4), ranging from a few inches to 3 or 4 feet with deeper holes, as in Baffin Bay.

Even though the average annual rainfall in this region is reported (Thornthwaite, 1948) to be about 25-27 inches, the area is classified as semiarid because evaporation exceeds precipitation by as much as 21 inches per year. Moreover, the average annual air temperature is 22°C with a range from -11°C to 40°C (Rusnak, 1960).

(2) Salinity. – The Laguna Madre of Texas is still classified as hypersaline (metahaline), i.e., having salinities ranging at least between 40 and 80°/oo. As will be pointed out in this section, however, several actions have been taken in recent years to reduce salinities with partial success.

TABLE A-4

DIMENSIONS AND BATHYMETRY OF LAGUNA MADRE

	Upper Laguna Madre	Baffin Bay	Saltillo Flats	Lower Laguna Madre
Total area (sq mi)	124.0	85.0	134.0	400.0
Area of water (sq mi)	120.0	–	0.0	270.0
Length (mi)	50.0	15.0	21.0	55.0
Ave. width (mi)	2.5	3.0	3.0	5.0
Ave. depth (ft)	2.5	5.0	0.0	2.5
Max. depth (ft)	6.0	12.0	0.0	8.0

(after Rusnak, 1960)

The metahaline conditions that do prevail here, especially in the northern Laguna, result from high rates of evaporation, shallow depths (large surface/volume ratio), and limited influx of both land runoff and Gulf waters. Until recently the Laguna was isolated from the Gulf except across a sill at Corpus Christi Bay in the north and through Brazos Santiago Pass in the south. Salinity extremes were more common than now. For instance, salinities in excess of 80°/oo were frequent, and in some years, especially in Baffin Bay, they soared to 113°/oo. On the other hand, cloudbursts of as much as six inches in the area, can bring abrupt reductions of surface salinity to as low as 2°/oo in the open water. Flooding of the southern Laguna through the Rio Grande can reduce salinities there to low levels (ca. 8°/oo) for periods as long as several weeks.

In recent years various alterations of the physical conditions in the Laguna have been undertaken by man. Several deliberate attempts have been made to reduce salinities by digging channels across Padre Island. One of these, Yarborough Pass, connects the northern part of the Laguna with the Gulf, but it has never materially reduced the lagoon's salinity. Up to the opening here (in the late 1940's) of the Intracoastal Waterway, which is 125 feet wide and 12 feet deep, the northern and southern parts of the Laguna were virtually separated, which resulted in separate hydrographic conditions except during periods of very high tides (Hedgpeth, 1953). The waterway, which runs the entire length of the Laguna, has ameliorated salinities somewhat, but the beneficial effect was offset somewhat by construction of the Corpus Christi Causeway to Padre Island. Thus, the principal value of the artificial channels and passes (so long as the latter have remained open) provides escape passages to the Gulf for fishes during high summer temperatures and salinities and during winter cold periods. To some extent, then, the spectacular mass mortalities of fish that have occurred here periodically seem to be less frequent. Hedgpeth (1967) reports that in spite of environmental stresses, the Laguna Madre is an important source of food (see Table A-3 also). Through construction in 1962 of a pass across Padre Island opposite Port Mansfield (southern Laguna) salinities in the southern Laguna are reported to fluctuate less drastically and the faunal assemblage is being altered by the invasion of species from the Gulf (Hedgpeth, 1967). Thus, the

activities of man have resulted in a situation where the salinities of the northern Laguna may be twice as high as the open Gulf, whereas those in the southern Laguna are only slightly higher than normal.

(3) Temperature. – Water temperatures have a wide seasonal range in the Laguna Madre, ordinarily from about 4°C in January to 33°C in August (Collier and Hedgpeth, 1950). Periodically, however, ranges from -11° to 40°C are recorded. Sorenson (1963) reports the formation of ice on the southern Laguna during the winter of 1962. Average water temperatures by month are shown in Figure A-5. These averages ranged from 10-29°C during the four years of 1964-1967.

(4) Tides. – Because the bays have such restricted connections with the Gulf of Mexico, periodic tides are virtually absent. Limited tidal effects of the Gulf are observed in Brazos Santiago Pass (leading to Port Isabel) and in parts of the Intracoastal Waterway, but these raise the water level locally no more than 12 to 18 inches. As is well known for this region, tides due to wind are of far greater magnitude than astronomical tides. Extremes of wind can cause a tidal range of more than 4 feet (Rusnak, 1960). As Copeland et al. (1968) point out, water levels in the shallow Texas bays and lagoons are of great ecological importance, since very small fluctuations of water level result in alternate flooding and draining of thousands of acres of productive mud (algal) flats and grass flats.

Hurricane surge tides have frequently exceeded 10 feet (Hayes and Scott, 1964).

(5) Winds. – Although the prevailing winds in this region come from the southeast across the Gulf of Mexico (Behrens, 1963), very strong winds from the northeast and east whip the Laguna in winter as cold fronts pass. From October to February the most important winds here have NE and E components, whereas throughout most of the rest of the year the strongest winds come from the SE and SSE. The prevailing winds have velocities generally ranging between 10 and 30 mph; "northers" may range up to 70 mph; and hurricane winds may exceed the latter by a factor of at least 1.5.

The monthly averages for winds off Brownsville, Texas range between 9.8 (Sept., Oct.) and 14.4 mph (April) with an annual average of about 12 mph (Brower et. al., 1972).

(6) Currents. – Water circulation in the Laguna Madre proper is controlled largely by wind-induced tides, which pile water up on one or another of the lagoon sides. Thus, typical estuarine circulation does not occur except near the mouth of Brazos Santiago Pass in the southern Laguna. The northern Laguna, including Baffin Bay, is essentially a closed basin since the exchange between the lagoon and Corpus Christi Bay is very limited. The latter bay may contribute considerable water to the lagoon during periods of high wind tides of winter. The usual condition is apparently that of small outward flow of Laguna water into the Bay in response to the prevailing SE winds (Rusnak, 1960).

Salinity data indicate that water exchanges are largely ineffective, that is, very little mixing occurs. For instance, salinity data reveal that some exchange of water between the southern Laguna and the northern basin takes place through the Intracoastal Waterway. Simmons (1957) shows, however, that even though water masses slosh back and forth in the basins under the influence of wind, very little mixing occurs between hypersaline and fresher waters because of density differences. As a result also any low density water that moves into the northern basin from Corpus Christi Bay remains on the surface and will move out again intact when the wind shifts to the SE quadrant.

In general, currents follow the winds so that when north winds blow, currents flow southward and vice versa. Sibul (1955) states that bottom currents flowing opposite to these tides have been observed in the Intracoastal Waterway.

(7) Storms. – Even though the Laguna Madre is subject to severe northerlies a few times per year during winter months, its most severe storms are hurricanes that move in from the SE quadrant. Price (1956) indicates that hurricanes can be expected to affect the area with a frequency of 40 times in a century. Data presented in Figure A-5 suggest that this estimate may be high. A compromise estimate places the frequency of hurricanes in the Laguna Madre at between once every 2.5 to 4.5 years. The last hurricane to seriously affect the area (northern part) was *Celia* in 1970, which made landfall in the vicinity of Corpus Christi. Weather records from 1900 to 1963 show that hurricanes passing near enough to cause flooding across Padre Island can be expected to occur somewhat less frequently. Price (1956) estimates the frequency to be about 18 times per century. One such occasion was the passage of hurricane *Carla* in 1961; its effects are described by Hayes and Scott (1964).

During *Carla* the foredune ridge of Padre Island was eroded back an *average* of 100 feet and breached by hurricane channels at many localities. In the lagoons, washover fans consisting of sand and shell eroded from foredunes, beaches, and inner shelf were constructed on the barrier bordering wind-tidal flats. These fans are associated with channels across Padre cut by the hurricane surge. Hayes and Scott (1964) report that a layer of pure mud, up to four inches thick, was deposited by *Carla* on the mainland bordering wind-tidal flats. The intervening lagoon, however, acted as an effective trap for the landward-moving coarse sediments (see Geology section of this report).

b. Geology

(1) Barrier Island Complex. – Tidal channel and tidal delta deposits are associated with passes that cut through barrier islands. Hayes and Scott (1964) point out that such passes are common on the Texas coast north of Port Aransas but not to the south. In fact, south of Aransas the barrier is at present virtually unbroken by "natural" passes. Corpus Christi Pass, located at the southern tip of Mustang Island, was a major natural pass in the 1920's, but has not been open in recent years except for brief intervals after hurricanes. Surficial deposits have largely obscured evidences of other natural passes. The lagoonal side of much of Padre Island is occupied by

active dune fields. According to Hayes and Scott (1964) the chief such features are sief dunes, which attain heights of 30 to 50 feet. Barchans are also present, but are of lower profile. The sediments of these dunes are well sorted fine sane with some fine shell hash derived from hurricane washover action.

(2) Lagoon-Bay Complex. – As pointed out earlier, the textural distribution of sediments within the semiarid hypersaline Laguna Madre forms a considerable contrast to the subhumid bays to the north and northeast. The northern Laguna and the barrier flats of the southern Laguna consist mainly of sands deposited by washover storm waves and by wind action from the barrier island (Rusnak, 1960). In general, these two areas are less than 2.5 feet deep, but deeper areas occur along the western side of the lagoon. It is these holes, the bay center facies, and the marine grassy areas at the lagoon extremities that act as sediment traps for finer material and thus contain clayey sand or silty clay deposits. Baffin Bay, which has numerous deep basins, behaves as a large settling basin for clays. This fine-grained material is apparently derived from intermittent streams, Corpus Christi Bay waters when they do get in, and erosion of outcrops and winnowing by waves from surrounding shallow areas (Rusnak, 1960).

The type of sedimentary structure depends upon the amount of bioturbination which in turn depends upon salinity controlled population densities of infaunal invertebrates. Hayes and Scott (1964) report that these structures range through a spectrum of well laminated clay and silt in the metahaline Baffin Bay to irregular distinct laminae, distinct mottling, and indistinct mottling where invertebrates are more common, as in the southern Laguna.

The metahaline conditions of parts of the Laguna result in the formation of minor deposits of chemically precipitated gypsum, carbonate aggregates and oölites. Rusnak (1960) indicates that shore lines have large concentrations of shell fragments that are partially cemented to form calcarenite deposits along the beach.

c. Chemistry

The following values for chemical parameters were compiled from Hahl and Ratzlaff (1972). The values for dissolved organic carbon (DOC) are given by Maurer and Parker (1972).

Values mg/l or as Given	Upper Laguna (Ranges)	Baffin Bay (Ranges)	Lower Laguna (Ranges)
pH	8.4- 8.9	8.2- 8.6	7.6- 8.7
O_2 (ml/l)	2.1- 8.0	3.5- 5.4	0.0- 6.4
BOD	5.3- 8.1	4.2- 8.0	0.8- 7.9
SiO_2	2.1- 6.8	10.0-12.0	0.3-15.0
NO_3	0.0- 0.1	0.0	0.0
NH_4	trace	trace	trace
NO_2	trace	trace	trace
Phosphate			
Orthophosphate as phosphorus	0.01-0.04	0.05-0.06	0.01-0.13
Total phosphorus	0.03-0.04	0.06-0.10	0.03-0.20
Secchi Disk (cm)	46-90	21-41	48-122
DOC	7.5-11.1	8.9-10.1	3.6-5.8

3. Resident and Transient Marine Biota

a. Attached Vegetation

(1) Key Species. – In the northern and southern extremities of the Laguna there are extensive patches of the angiosperm *Diplanthera wrightii*, which is commonly called shoalgrass (Parker, 1959). Turtle grass, *Thalassia testudinum*, apparently is limited to South Bay in the southern Laguna. *Ruppia maritima*, widgeon grass, is reported by Hedgpeth (1967) to be common along the Intracoastal Waterway. The flats in many parts of the Laguna Madre are covered with algal mat communities that, according to Sorenson and Conover (1962), consist mostly of the blue-green alga *Lyngbya confervoides*.

Sorenson (1963) found *Penicillus capitatus* flourishing in the southern parts of the Laguna but only when temperatures and salinities were sufficiently high. Breuer (1962) reported scattered patches of *Acetabularia crenulata, Enteromorpha, Cladophora,* and extensive developments of the macroscopic alga *Gracilaria blodgetti* in the lower Laguna.

Baffin Bay presents a special case, for the principal plant life here is microscopic. Reports of very sparse developments of shoalgrass and macroscopic algal mats have been published occasionally. The diatom flora of the Laguna Madre is varied but presents little or no endemicity. Ferguson Wood (1963) reports 129 diatom species from all parts of the Laguna and states that seven of the 33 species found in Baffin Bay do not occur in other parts of the Laguna Madre but do occur in Corpus Christi and Aransas Bays.

(2) Seasonality. – The plant life of the Laguna is, according to Hedgpeth (1967), highly seasonal, dying down during the high summer temperatures (August and September) and remaining dormant until late winter or spring. The macroscopic algae begin to grow in February and the angiosperms commence growing in March.

b. Zoobenthos

(1) Key Species. – Under zoobenthos we shall refer solely to invertebrate animals in this part of the report. Whether or not a fish species is demersal and therefore might qualify as zoobenthic rather than pelagic is considered unimportant to the objectives of this report in the Laguna Madre.

Crustaceans of several species are abundant at times in the Laguna. Perhaps, however, their chief contribution to the bio-economy is as the significant part of the food for several species of fishes. The most important of these crustaceans are such brachyuran crabs as *Callinectes sapidus* (common blue crab) and the mud crab *(Neopanope texana).* Abundant also at times are the young of the penaeid shrimp, *Penaeus aztecus* (browns), and the grass shrimp, *Palaemonetes intermedius.*

A few species of clams are common in various parts of the Laguna. According to Hedgpeth (1967) the most abundant of these are *Anomalocardia cuneimeris, Mulinia lateralis,* and *Tellina tampaensis.* The grass-supporting areas of the Laguna support such bivalves as *Brachidontes exustus, Aequipecten irradians amplicostatus,* and *Chione cancellata.* Most of these bivalves constitute major elements in the diet of the black drum fish.

(2) Virtual Absence of the Oyster Community. – The very characteristic oyster community present in the bays of central and northeastern coastal Texas is for all practical purposes absent from the Laguna Madre. According to Hedgpeth (1953), *Crassostrea virginica* builds reefs when the following three environmental conditions obtain: (1) a range of temperature means between 10-25°C, (2) regular influx of fresh water and (3) a salinity range no more than from 10-30°/oo on a usual basis. Much of the Laguna Madre does not meet one or more of these conditions. Even though small oyster communities are found near Port Isabel at the southern end of the Laguna Madre, Hedgpeth (1953) emphasizes that the biotic composition of these beds is markedly different from those in more northerly bays. The principal difference is that the associates of the oyster here are marine rather than estuarine as is true elsewhere. Thus, some of the predominant species, in addition to *Crassostrea virginica,* are the brittle starfish, *Ophiothrix angulata,* the brown anemone, *Aiptasia pallida,* and the sea cucumber, *Thyonacta sabanallensis,* all of which are absent from the bays farther north even though they are found offshore.

c. Pelagic Fauna

(1) Zooplankton. – The most abundant zooplankters in many parts of the Laguna, including Baffin Bay, are the copepods *Acartia tonsa* (up to 7 million/liter), Simmons, 1957) and *Metis japonica* (up to 1 million/liter). *Acartia* is important as a food item for small fish, but apparently the *Metis* is not (Hedgpeth, 1967).

(2) Ichthyofauna. – The great abundance and variety of fishes occurring in the Laguna is documented by Simmons (1957). He lists some 70 species of fishes that have been collected in the Upper Laguna Madre. It should be emphasized, however,

that only 10 or so of these species spawn here and thus can be considered as residents of the Laguna. Among these resident species are the black drum *(Pogonias cromis)*, the spotted sea trout *(Cynoscion nebulosus)*, the mullet *(Mugil cephalus)*, and the skipjack *(Elops saurus)*. Many other species of fish spend considerable time in the Laguna but leave in summer during major rises of temperature and salinity. Two of the most important species in both sports and commercial fisheries in the bays of Texas are the redfish, *Sciaenops ocellata*, which does not spawn in the Laguna, and the black drum that does.

d. Bioproductivity of the Laguna Madre

(1) Contribution to the Finfishery of Texas. – In spite of the existence of extremes of most environmental parameters, as detailed above, the Laguna Madre contributes more than 50 percent of the total catch from Texas coastal waters in most years. This percentage may rise if a solution is not found to the malodorous state of fishes freshly caught from some of the more northerly Texas bays.

(2) Mass Deaths of Organisms from Natural Causes. – Prior to construction of the Intracoastal Waterway, fish mortality of two types occurred in the Laguna, namely, mortality caused by hypersalinity, and more serious kills caused by sudden drops in water temperature. According to Simmons (1957) kills from hypersalinity were reduced by the waterway, primarily because fish can leave the area. Mass mortalities from cold water are a repeated event in the history of the Laguna Madre and other points along the Texas coast. Major freezes are said to occur on average about every 14 years, but four severe freezes are on record between 1940 and 1951. In a severe freeze millions of pounds of dead fish are estimated to line the beaches. There is reason to believe that many invertebrate species are also severely affected. Fish populations are apparently able to recover from these setbacks in about three years, probably as a result of recruitment from the Gulf or from some of the deeper estuaries. Complete recoveries cannot occur in shorter time spans because food organisms, usually invertebrates that suffer mortalities also, have recovery lags as great as or greater than those of the fishes.

e. Marine Birds and Mammals

The waters of the Laguna Madre are the wintering habitat for about 500,000 waterfowl (McMahan, 1968; Lynch, 1968). This figure includes about 78% of the North American population of Redhead Ducks (Weller, 1964). Pintail and Widgeon ducks also use the Laguna Madre as feeding grounds between November and February (Koenig, 1969).

Long-legged wading birds (Herons and Egrets) use these waters for year-round habitat. Terns, gulls, egrets, skimmers, and herons nest on the spoil islands along the Intracoastal Waterway during the spring and early summer months. Simmons (1957) reports that most of the above avian species feed on small fish in the Laguna.

The marsh areas of this zone are the prime habitat of the Mottled Duck, but it also occurs in Zone II.

Marine mammals in the waters adjacent to Padre Island include beaked whale, sperm whale, pygmy sperm whale, bottle-nosed dolphin, spotted dolphin, Atlantic killer whale, and short-finned blackfish (National Park Service, 1971).

f. Rare and Endangered Species

Rare and endangered species are not listed here. Their critical region is included in part of Zone II.

4. Man's Activities

a. Residential, Business, and Industrial Developments

Pertinent information on human developments within Zone I is condensed in Table A-5.

TABLE A-5

POPULATION AND BUSINESS DEVELOPMENTS IN ZONE I

City or Town	1970 Population	No. of Business Establishments*	Remarks
Brownsville	52,522	688	International seaport (via 17-mile Brownsville Ship Channel), airport, and railroad interchanges. Fishing harbor and processing plants. Port of entry to Mexico at Matamoros.
Port Isabel	3,067	110	Seaport and distribution point for petroleum products, center for large shrimping and finfish industry, fish and shrimp processing plants.
Port Mansfield	731	?	Listed as a deep-water port (Miloy and Blake, 1970); principal port traffic in fuel oil & gasoline. One fishery processing plant located here in 1968 (Miloy and Copp, 1970).

*Number of rated business establishments that are given a rating by Dun and Bradstreet.

(Datafrom Texas Almanac, 1972; Texas Highway Dept., 1970; AAA, 1971).

b. Fisheries

As shown in Table A-3, the bays of Zone I (Baffin Bay, Upper and Lower Laguna Madre) account for a greater dollar value of finfish catch ($388,000 in 1968) than any other Texas bay area. This area has the lowest dollar value for shellfish catch, however.

Of the 163 processing plants of fishery products in the Texas coastal zone listed by Miloy and Copp (1970), 46 are located in Zone I compared to 108 in Zone II and 9 in the Texas portion of Zone III. Miloy and Copp also point out that, as might be expected, most wholesale dealers in fishery products are located in close proximity to processing firms. A total of 152 wholesale dealers were in business in the Texas coastal area in 1968. Brownsville (Zone I), with 22, had the greatest number of wholesale dealers followed by Freeport (Zone II) with 14 firms, and Port Isabel (Zone I) with 13.

In spite of the fact that the bays of Zone I produce the lowest dollar value for shellfish catch, the ports of Zone I have higher shrimp landings than any other Texas ports. This, of course draws on shrimp catches from the open Gulf of Mexico, outside the bays of Zone I itself. In 1970 the Brownsville-Port Isabel area led all Texas ports in shrimp landings with 32.5 million pounds of shrimp or 37% of the state's commercial landings, followed by Aransas Pass-Rockport in Zone II (21%), Freeport in Zone II (19%), and Galveston Bay ports in Zone II (12%) (Texas Landings, 1971).

(1) Brownsville. – A fishing harbor is located here that accommodates about 600 vessels and provides shoreside processing, freezing, and holding plants. In 1968 there was a total of 23 firms processing fishery products in Brownsville and 22 wholesale dealers in fishery products.

(2) Port Isabel. – This city supports a large shrimp and fish (especially red snapper) industry with 16 fishery processing plants in 1968 and 12 wholesale dealers in fishery products. It also provides the base for a big-game fishing area offshore for open-ocean fish.

c. Recreation and Leisure

(1) General Tourist Areas.

(a) Port Isabel. Big-game fishing area for sailfish, marlin, tarpon, mackerel, tuna, and dolphin (Texas Highway Dept. Tourist Information Bureau, 1970). Charter boats for open-ocean fishing trips. Causeway connects Port Isabel with Padre Island.

(b) Padre Island and Laguna Madre. Tourist areas for fishing, boating, swimming, water skiing, picnicking, and camping. County parks on Padre Island outside the National Seashore area offer bathhouses, campgrounds, and picnicking areas.

(2) National Refuges and Recreation Areas (Figure A-10).

(a) Laguna Atascosa National Wildlife Refuge. Located approximately 20 miles north of Port Isabel on the Laguna Madre. Contains 45,147 acres devoted to tour roads, trails, and blinds for nature study, photography, and sightseeing. Also fishing, boating, and camping available. Wintering area for ducks and geese. List of principal species includes geese, ducks, herons, ibises, shore birds, terns, cranes, white-tailed hawks, white-tailed kites, and doves (U.S. Fish and Wildlife Service, 1972). No hunting allowed. 40,000 visitors in 1971.

(b) Padre Island National Seashore. An 80-mile strip comprising 134,000 acres along the middle of the 113-mile-long Padre Island barrier island was designated as a National Seashore in 1968. The National Seashore extends from south of Corpus Christi to Mansfield Channel opposite the town of Port Mansfield (Pop. 731). The waters of the Laguna Madre, part of the Intracoastal Canal, border it on the west and the open Gulf on the east. Leisure activities including swimming, surfing, SCUBA diving, water skiing, fishing, and bird watching were enjoyed by over 700,000 visitors in 1969. The sand island boasts very few shrubs and trees, but several hundred species of grasses and wildflowers are common. Over 350 species of birds are residents or seasonal visitors including great blue herons, sanderlings, pelicans, and several species of gulls and terns as permanent residents. Migrators include large numbers of ducks and geese as well as sandhill cranes. Other vertebrate animals on Padre Island include coyotes, black-tailed jackrabbits, gophers, and lizards. Surf-fishing for flounder, shark, redfish, pompano, black drum, and ocean trout is a popular tourist activity (Duerr, 1972).

(3) State and County Parks and Recreation Sites.

(a) Brazos Island State Scenic Park. Two hundred seventeen acres of excellent beach; located southeast of Port Isabel. Development is not completed yet and acquisition of more land is expected (Reed and Reid, 1969).

(b) Port Isabel Lighthouse. This 1-acre State Historical Site, is located in Port Isabel.

E. ZONE II – THE BAYS OF CENTRAL TEXAS

Zone II, extending from Corpus Christi Bay in the southwest to beyond Galveston Bay in the northeast, is a complex zone made up of numerous bays and associated estuarine systems (Figure A-1). For convenience in this report, Zone II has been subdivided into five bay and estuary systems: 1) Corpus Christi Bay, 2) Aransas Bay, 3) San Antonio Bay, 4) Matagorda Bays, and 5) Trinity River Estuary (Galveston Bay). These five areas are treated separately in regard to physical and biological characteristics. Man's activities, however, are presented for the entire Zone II at the end of the separate sections on the five bays.

1. Corpus Christi Bay

a. Summary

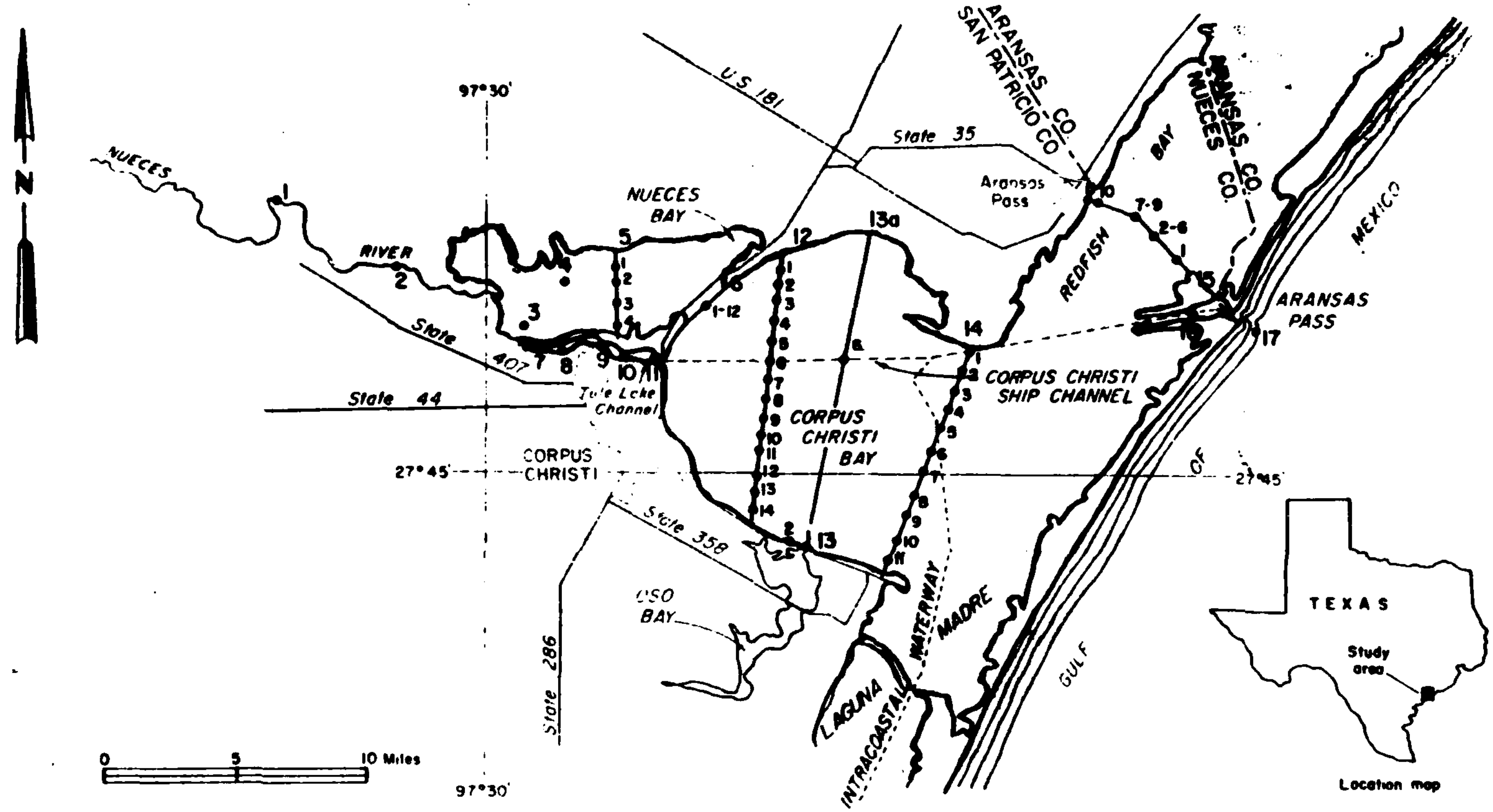
The most significant components of the Nueces River estuary are Nueces and Corpus Christi Bays (Figure A-12). The entire estuarine complex which also includes Aransas Pass and part of the Intracoastal Waterway, covers an area of 115,200 acres (180 square miles). Corpus Christi Bay has an area of about 96,000 acres: Nueces Bay has an area of 19,000 acres. The estuary is separated from the Gulf of Mexico by Mustang Island, which is a northern extension of Padre Island. The major entrance to the estuary is Aransas Pass, which is about 2400 feet wide and some 40 feet deep.

Under usual conditions the Nueces River introduces between 610 and 620 thousand acre-feet of freshwater into the system per year. A water conservation project resulted in the construction of Lake Corpus Christi, which may reduce the above flow substantially from year to year. Salinities over all stations in Corpus Christi Bay average about 31°/oo, but are considerably higher in Nueces Bay.

The Corpus Christi Bay area lies on the transition belt between the arid and dry subhumid climatic zones. The annual precipitation in Corpus Christi averages only 28.3 inches. Furthermore, annual evaporation exceeds this by at least 17 inches, making the entire region one with a severe water deficit. The annual average air temperature is 70.5°F. The mean maximum air temperature is 94°F and the mean minimum is 47°F. The prevailing winds are southeasterly with a mean speed of 11.9 mph. Hurricanes with winds up to 180 mph have been reported over the area in 1916, 1919, 1961, and 1970. Normal astronomic tides are diurnal and average less than a foot. Exceptional storm surges have been recorded in association with tropical cyclones. The largest on record is 16 feet, and it is quite likely that even higher tides occurred with *Celia* in 1970, but no accurate reports are available.

At the present time Corpus Christi Bay produces very small amounts of seafood products. In 1970, for instance, it ranked last in oyster production (none) for Texas along with Sabine and Upper Laguna Madre; it ranked 5th in shrimp production, far behind San Antonio Bay in 4th place; it ranked last in crab production (none) along with Lower Laguna Madre; and it ranked 7th (out of 8) in finfish production.

It would appear that the most damaging factors controlling the future bio-productivity of Corpus Christi Bay are the potential for steadily rising salinities and industrial waste levels. These parameters, which have been rising steadily under the influence of water development and population increase, are present problems. They probably outweigh the potential damage of offshore oil spills, largely because of the limited access of Gulf waters to the estuarine complex.



(NUMBERS REPRESENT WATER SAMPLE COLLECTION SITES OF HAHL AND RATZLAFF 1970, 1972)

Base by U.S. Geological Survey, 1956

FIGURE A–12 CORPUS CHRISTI BAY

b. Physical Characteristics

(1) Hydrology.

(a) Physiographic. – Corpus Christi Bay is the major port of the Nueces estuary. This estuary covers an area of about 180 square miles and consists of the tidal part of the Nueces River, Nueces Bay, Tule Lake Channel, Corpus Christi Bay, Aransas Pass, and parts of the Intracoastal Waterway.

Water depth at mean low water is less than 13 feet in Corpus Christi Bay; less than 3 feet in Nueces Bay; more than 40 feet in Aransas Pass, Corpus Christi Ship Channel, and about 15 feet in the Intracoastal Waterway (Hahl and Ratzlaff, 1972).

Corpus Christi Bay proper has an area of about 150 square miles and a shoreline of about 61 miles; Nueces Bay covers 30 square miles and has a shoreline of 33 miles. At mlw these bays are estimated to have volumes of 993,000 and 46,000 acre-feet, respectively.

Corpus Christi Bay is situated on the dividing line between the semiarid and dry subhumid climatic zones. Annual rainfall averages about 28-30 inches (Figure A-2), but evaotranspiration exceeds this by at least 16-18 inches. Corpus Christi Bay is undergoing considerable change in water quality as a result of Nueces River development. The holding of water in Lake Corpus Christi appears to have increased the salinity of Nueces Bay up to as high as 55°/oo. Corpus Christi Bay has practically no other source of runoff than the Nueces River. Annual average runoff has reduced from about 610,000 to 505,000 acre-feet per year. According to Lockwood et al. (1967), if contemplated further developments are realized, there will be no river flow into Corpus Christi in 13 out of 16 years.

(b) Salinity. – It appears from data provided by Hahl and Ratzlaff (1972) and Hood (1953) that the surface salinity of Corpus Christi Bay ranges somewhere between 27°/oo and 45°/oo. As indicated above that of Nueces Bay has been measured as high as 55°/oo. These figures place both bays in the metahaline category. The average salinity of Corpus Christi Bay in 1966 was 30.5 and 31.5°/oo in 1967 (Coastal Fisheries, Project Report for 1967).

(c) Temperature. – Surface water temperatures of Corpus Christi Bay range between 15.2°C in January to around 31.0°C in August.

(d) Tides. – The diurnal range of tide at Aransas Pass is 1.7 feet. Winds do not generally have as much influence on water levels in this vicinity as in other points along the Gulf but may cause fluctuations of 1.5 to 3 feet above and below mean low water (Brower et al., 1972). Exceptional storm surges have been recorded in association with tropical cyclones. The greatest of these caused a high water mark 16 feet above mean sea level (Brower et al., 1972).

(e) Wind. – The surface winds of Corpus Christi area are dominated by the general circulation of the Bermuda High throughout the year. Brower et al. (1972) report that the prevailing direction is southeast in all months except September, which is easterly. August has the maximum monthly average of 11 mph, but also has the maximum measured wind speed of 180.0 mph.

(f) Currents. – In Corpus Christi Bay, as is true of others on the Texas coast, the direction and speed of the principal currents are functions of wind. Under influence of the prevailing southeasterlies, the principal flow is westward past the entrance to Nueces Bay and the City of Corpus Christi (Hood, 1953). During a "norther" the principal flow is south by east.

(g) Flushing. – Hood (1953) estimated that it could take as long as 1200 days to replace all of the water of Corpus Christi Bay with Gulf Water. This rate, however, depends in large part upon the rate of fresh water inflow, and to a lesser extent upon the rate of evaporation from the bay surface. If Lockwood et al. (1967) are correct that future developments of Lake Corpus Christi waters will prevent river flow into Corpus Christi in 13 out of 16 years, Corpus Christi will become the most metahaline bay of Texas.

(h) Storms. – The proximity of Corpus Christi and Aransas Pass makes it appropriate to list major storms in the area only once. Many hurricanes are very large and thus bring severe winds to a wide area of the coast. For instance, Hurricane *Carla*, the largest on record, damaged the Texas coast from Corpus Christi to Port Arthur, a distance of nearly 200 miles. Listed here are those hurricanes that passed more or less directly over the above bays:

August 18, 1916	Maximum wind, 100 mph
September 14, 1919	Maximum wind, 110 mph Tides 16 ft above normal
September 8-14, 1961	Unknown
August 3-5, 1970	Maximum winds, 180 mph

Brower et al. (1972) indicate that winds of hurricane force (over 70 mph) were observed in 25 separate storms between 1899-1971, but all of these are not listed above because their more direct and damaging effects are noted elsewhere.

(2) Chemistry

Data on water chemistry of Nueces Bay and Corpus Christi Bay were taken from Hahl and Ratzlaff (1972). The range of dissolved organic material in Corpus Christi Bay was obtained from Maurer and Parker (1972).

Values are in mg/l except for dissolved O_2 (ml/l) and organic carbon (mgC/l).

	Neuces Bay	Corpus Christi Bay
pH	8.1-8.2	8.0-8.5
O_2	5.0-5.7	2.4-6.9
BOD	2.2	1.0-5.0
SiO_2	2.6-2.7	0.8-3.0
NO_3	0.0	0.0-0.5
NH_4	–	–
NO_2	–	–
Phosphate		
Orthophosphate	0.02-0.05	0.01-0.22
Total phosphate	0.06-0.08	0.02-0.36
DOC	–	4.2-5.9
Secchi Disk (cm)	20-25	33-135

c. Resident and Transient Marine Biota

(1) Attached Vegetation

Key Species. – The heaviest growth and greatest variety of attached algae occurs along the eastern portion of Corpus Christi Bay. The flowering plants also grow well on the eastern saltflats and along the shorelines of spoil banks. Stevens (1961) found that the bottom characteristics of a large part of Corpus Christi Bay are not suitable for optimum growth of attached plants.

The principal algae presented by Stevens (1961) are *Acetabularia crenulata, Enteromorpha flexuosa, Gracilaria caudata, Gracilaria foliifera,* and many others.

The most important marine flowering plants on the eastern shore found by Stevens (1961) and listed by Edwards (1970) are *Halophila engelmannii, Thalassia testudinum, Diplanthera wrightii, Cymodocea filiforme, Salicornia bigelovii,* and *Spartina alterniflora.*

(2) Zoobenthos

In 1970 Nueces and Corpus Christi bays did not produce commercial quantities of blue crab (*Callinectes sapidus*) or oyster (*Crassostrea virginica*) or the high salinity oyster *Ostrea equestris* (Texas Landings, 1971). Its largest seafood product was the white shrimp (*Penaeus setiferus*) followed by the brown shrimp (*Penaeus aztecus*). Even so its shrimp production of about 346,000 pounds in 1970 ranked it 5th in the shrimp fisheries of Texas bays.

(3) Pelagic Fauna

Ichthyofauna. – As is true of most of the bays of Central Texas, the principal sports and commercial finfish of the Corpus Christi Bay System are the redfish, *Sciaenops ocellatus;* drum, *Pogonias cromis;* trout, *Cynoscion nebulosus;* sheepshead, *Archosargus probatocephalus;* and flounder, *Paralichthys lethostigma.* It

should be pointed out, however, that in 1970 Corpus Christi and Nueces bays ranked next to last (7th) in finfish production (Texas Landings, 1970). On the basis of poundages, the leading species in 1970 were redfish, spotted sea trout, and drum.

2. Aransas Bay

a. Summary

Aransas Bay and Copano Bay are the most important parts of the estuary formed by the Aransas and Mission Rivers (Figure A-13). This estuarine complex covers about 125,000 surface acres of land and water bayward from the mean high tide line. About 30,000 acres of the estuary are estimated to be salt flats and marshes. St. Joseph Island, part of the Texas barrier island chain, separates Aransas Bay proper from the Gulf of Mexico. The most direct connection the estuary has with the Gulf of Mexico is via Aransas Pass at the south end of Aransas Bay. To the north the latter interconnects with San Antonio Bay via Carlos and Mesquite bays.

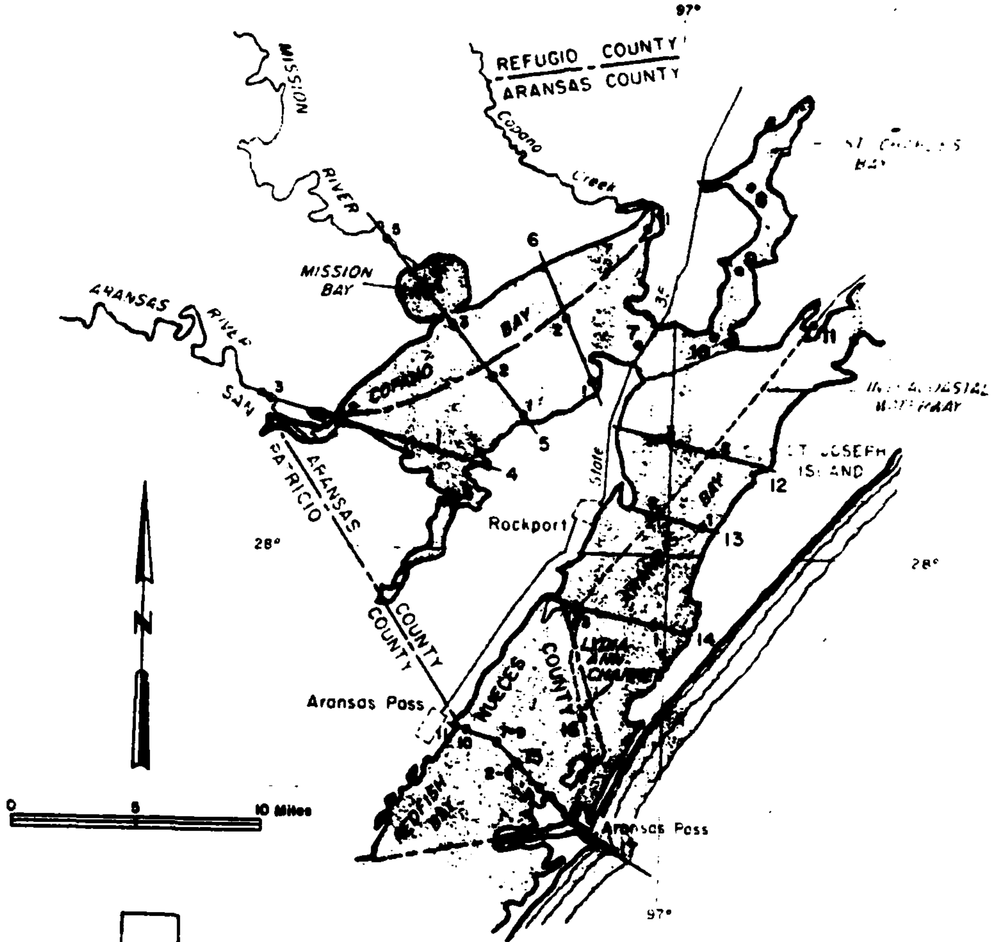
The Mission and Aransas Rivers and Copano Creek contribute about 160,000 of the estimated 173,000 acre-feet of fresh-water inflow entering the estuary annually. It is estimated, however, that most of the less saline waters enter the estuary from the east through the Intracoastal Waterway. Salinity concentrations in the estuary average about 20 parts per thousand.

Sediment inflow to the estuary is light, and much of it is trapped by Copano Bay before water enters Aransas Bay. The bay bottoms consist of sand and shell and are covered by a thin layer of mud.

The climate in the estuary is semi-tropical. The annual precipitation is about 33 inches, but evaporation exceeds this by about 14 inches. As a consequence the climatic zone is classified as dry subhumid. The annual average air temperature is 71.8°F. Prevailing winds are southeasterly with an average velocity of 13 mph. High velocity "northers" occur in the region, primarily in the month of December. Hurricane winds of up to 161 mph have been measured in the area as recently as 1970.

Normal astronomic tides are diurnal and average about 1.7 ft in Aransas Pass and 0.5 ft or less in the bays. Wind-induced tides are of far greater magnitude.

Fish habitat in the estuary is of great importance. It is estimated that the estuary produces annually about 850 pounds of catch-size fishes, crustaceans, and oyster meats per acre. The fishes, such as sea trout, redfish, drum, etc., and some crustaceans (white shrimp, brown shrimp, and blue crab) use the estuarine complex as a breeding, feeding, and nursery habitat. The shallow vegetated shoreline areas are used extensively as nursery grounds. Oyster reefs also comprise an important fish feeding habitat. The Aransas estuary is the third most important producer of estuarine seafood products in Texas. (*National Estuary Study*, Vol. 3, pg. 189)



Numbers represent water sample collection sites of Hahl and Ratzlaff 1970, 1972.

Base by U.S. Geological Survey, 1956

FIGURE A–13 ARANSAS-COPANO BAY

The estuary is very important as a wintering area for waterfowl, shore, wading, and other migratory birds. The most famous of the endangered species, the whooping crane, winters here. In fact, about one-third of all winter habitat for the whooping crane is located in this estuary.

About one-half of the shoreline of the Aransas National Wildlife Refuge borders the Aransas estuary. Thousands of people visit the refuge each year primarily to see the whooping crane.

The habitat and activities most vulnerable to oil-spill damage in the lower part of this estuary are:

(1) The Aransas National Wildlife Refuge and the thousands of birds that breed or winter there, and

(2) The marsh areas that provide important contributions to the welfare of sports and commercial fisheries.

b. Physical Characteristics

(1) Hydrology

(a) Physiographic. – Aransas Bay is the most important component of the Aransas-Mission estuary. This estuarine complex consists of the tidal parts of Aransas River, Mission River, Copano Creek, and other tributaries; Aransas Bay; Mission Bay; Copano Bay; St. Charles Bay; parts of the Intracoastal Waterway; Lydia Ann Channel; and Aransas Pass (Figure A-13).

This estuarine complex encompasses about 125,000 surface acres of land and water bayward from the mean high tide line. Roughly 30,000 acres of the estuary are salt flats and marshes. St. Joseph Island is the chief barrier island separating the estuary from the Gulf of Mexico.

Water depth at mlw is less than 2 feet in Mission Bay, less than 8 feet in Copano Bay, less than 13 feet in Aransas Bay, less than 5 feet in St. Charles Bay, about 15 feet in the Intracoastal Waterway, about 20 feet in the Lydia Ann Channel and more than 40 feet in Aransas Pass.

Aransas Bay lies in the dry subhumid climatic zone (Figure A-4). The annual precipitation averages about 33 inches (Figure A-2), but evapotranspiration exceeds precipitation by about 14 inches (Figure A-3).

(b) Salinity. – Aransas Bay is isolated from the immediate effects of river drainage by Copano Bay, which receives both the Aransas and Mission Rivers. Together these rivers discharge only about 160,000 acre-feet of freshwater into Copano Bay per year (Martinez, 1967). The lower (southern) end of Aransas Bay receives water directly from the Gulf of Mexico via Aransas Pass, and is thus the high

salinity area of the bay. As a result of these connections, surface salinities undergo a marked reduction from about 23°/oo to 9°/oo along a line from lower Aransas Bay to Copano Bay at the Aransas River delta region. Summer increases in salinity in Aransas Bay result largely from high tides in August and September and the resultant invasion of saline Gulf water. During the four years from 1964 to 1967, monthly averages of surface salinity ranged from about 15 to 22.5°/oo (Figure A-6).

(c) Temperature. – Surface water temperatures in Aransas Bay range from about 9°C in January or February to 30.0°C in August. Monthly averages for the four years 1964 to 1967 show a low of 13.5°C in February to 29.5°C in July. The annual range of monthly averages is 16.5°C in Copano Bay from a low average of 13.4°C in January to a high average of 29.9°C in July and August (Collier and Hedgpeth, 1950). There is seldom more than a one degree difference between surface and bottom temperatures.

(d) Tides. – The tidal range in Aransas Pass is seldom more than 1.7 feet and is frequently no more than 0.5 foot within the bays. Wind tides of course, are characteristically much larger when extreme conditions persist.

(e) Winds. – The prevailing winds in the Aransas complex are southeasterly and south southeasterly. These average about 13 mph with a monthly range from 10 to 15 mph. Hence, as elsewhere in the region, "northers" occur a few times each year and bring high velocity gusts that have substantial effects in tidal levels, currents, and flushing of the embayments. Hurricane winds up to 125 mph have been recorded in the area (Brower et al., 1972).

(f) Currents. – Parker (1959) states that current velocities of slightly more than 1.2 kts were obtained when winds were blowing either north or south at more than 9 mph. Measurements of current velocity at the entrance to Copano Bay indicated a current moving out of Copano Bay in response to a northeast wind at a velocity of 0.17-0.37 kt. Strong currents were observed in Lydia Ann Channel during periods of strong winds from the north and south.

(g) Storms. – Please see the information given under this category for Corpus Christi Bay.

(2) Geology

In an extensive portion of Aransas Bay, the nature of the sediments indicates that they are accumulating very slowly (Shepard and Rusnak, 1957). This portion of Aransas Bay lies at a considerable distance from any stream mouth and it is too far inside the Bay to be influenced much by Aransas Pass flow. Most of the sediment-laden water entering the Bay through the Pass moves along the north and south shores before moving into the middle. As Parker (1959) states, this flow is documented by the presence of predominantly Gulf invertebrates at the Bay margins, and their absence in the center or upper reaches of Aransas Bay. According to Hedgpeth (in Parker, 1959), the movement of water is strongest along the north shore, which is characterized by a much wider band of coarse sediments.

The adjacent barrier island does not have many migrating dunes or excess supply of sand. The relatively deep water, much of it over 12 feet, prevents wind chop from introducing large quantities of sediments from the shallow margins. As a result of slow sediment accumulation, the benthonic foraminifers constitute an appreciable fraction, whereas quartzose sand percentage is diminished (Shepard and Rusnak, 1957).

Except for oyster reefs near its connection with Copano Bay, Aransas Bay has a regular bottom that is composed of silty clay in the center (Gunter, 1945), and of hard sand or fine shell with marshy areas on Mud Island and other islets to the west.

(3) Chemistry

Apparently only fragmentary data are available on chemical parameters in Copano Bay and Redfish Bay. These are summarized below (all values are in mg/l, unless otherwise conventional or specified).

Nutrient or Other Factor	Copano Bay	Redfish Bay
pH	8.0-8.4	7.9-8.6
O_2 (ml/l)	5.6-8.5	3.6-6.0
BOD	–	0.8-1.9
SiO_2	5.0-8.8	1.2-2.4
NO_3	3.0-8.5	0.0
NH_3	–	negligible
NO_2	–	negligible
PO_4		
Ortho	–	0.02-0.03
Total	–	0.03-0.05
Secchi Disk (cm)	31-41	81-145

(All of the above from Hahl and Ratzlaff, 1970).

DOC (mgC/l)	3.7-5.3	3.7-4.7

(Dissolved organic carbon from Maurer and Parker, 1972).

The O_2 content of the water in Aransas Bay is almost always near saturation and there usually is sufficient wind to prevent stratification (Lane, 1967).

c. Resident and Transient Marine Biota

(1) Attached Vegetation

Key Species. – Dense growths of widgeongrass (*Ruppia maritima*) fringe some shallow waters of the estuary. Redfish Bay has been noted for its extensive beds of turtle grass (*Thalassia testudinum*) and shoalgrass (*Diplanthera wrightii)*. Extensive

marshes are found on the southeast shore of Aransas Bay (St. Joseph Island). The importance of these marshes and grass beds to the fisheries of Texas are well documented. Schultz (1961) discusses the distribution of juvenile fish and shrimp in such beds. Hoese and Jones (1963) have established the high densities of juvenile animal populations in these shallow flats.

It is estimated that the Aransas complex produces about 850 pounds of mature fishes, crustaceans, and harvestable-sized oyster per acre annually. In large measure this production is dependent upon grass beds and marshes.

(2) Zoobenthos

Key Species. – The southern half of Aransas Bay and parts of Copano Bay, Mission Bay, and Port Bay are important habitat for such crustaceans as white shrimp, brown shrimp, and blue crabs. Oysters (*Crassostrea virginica*) develop best in Copano Bay, but some oyster reefs are found in northern Aransas Bay. Although several species of bivalve mollusks exist in the Aransas complex, the low-salinity oyster reef is the most important bivalve assemblage. Today, however, the production of oysters from the Aransas complex does not match that of such bays as San Antonio or Galveston.

The Aransas Wildlife Refuge area is an excellent nursery habitat for young brown shrimp. Juvenile shrimp appear in the bay in April and May. Emigration begins near the end of May. Heavy recruitment goes on in this area into September. Some young shrimp are found in the area through mid-December.

Common associates of oyster reefs in Aransas and Copano Bays found in Heffernan (1961) are:

Cliona celata. Boring Sponge
Microciona prolifera. Red Sponge
Astrangia astreaformis. Solitary Coral
Membranipora sp. Ectoproct
Bugula sp. Ectoproct
Brachidontes exustus. Bivalve (mussel)
Mercenaria mercenaria. Quahog clam
Chione cancellata. Cross-barred venus clam
Anomia simplex. Jingle shell
Arca transversa. Transverse ark
Crassostrea virginica. Oyster
Anachis avara semiplicata. Gastropod
Crepidula plana. Gastropod
Thais haemastoma. Gastropod
Polydora websteri. Polychacte worm
Dexiospira sp. Polychacte worm
Palaemonetes intermedius. Grass shrimp
Pagurus longicarpus. Hermit crab

Pagurus pollicaris. Hermit crab
Clibanarius vittatus. Hermit crab
Crangon armillatus. Pistol shrimp
Petrolisthes armatus. Porcelain crab
Callinectes sapidus. Blue crab
Panopeus herbsti. Crab
Eurypanopeus depressus. Crab
Menippe mercenaria. Stone crab
Pinnotheres ostreum. Pea crab
Balanus improvisus. Barnacle

(3) Pelagic Fauna

Ichthyofauna. – The principal fishes using the Aransas estuarine development are spotted seatrout, sand seatrout, red drum, black drum, southern flounder, croaker, mullet, sheepshead, gafftopsail catfish, whiting, menhaden, spot, and anchovy. These fishes use the estuary as breeding, feeding, and nursery habitats. As stated above, the nursery habitat includes the shallow vegetated shoreline areas. The oyster reefs are an important fish feeding habitat. The estuary is a moderately important source of finfish income.

3. San Antonio Bay

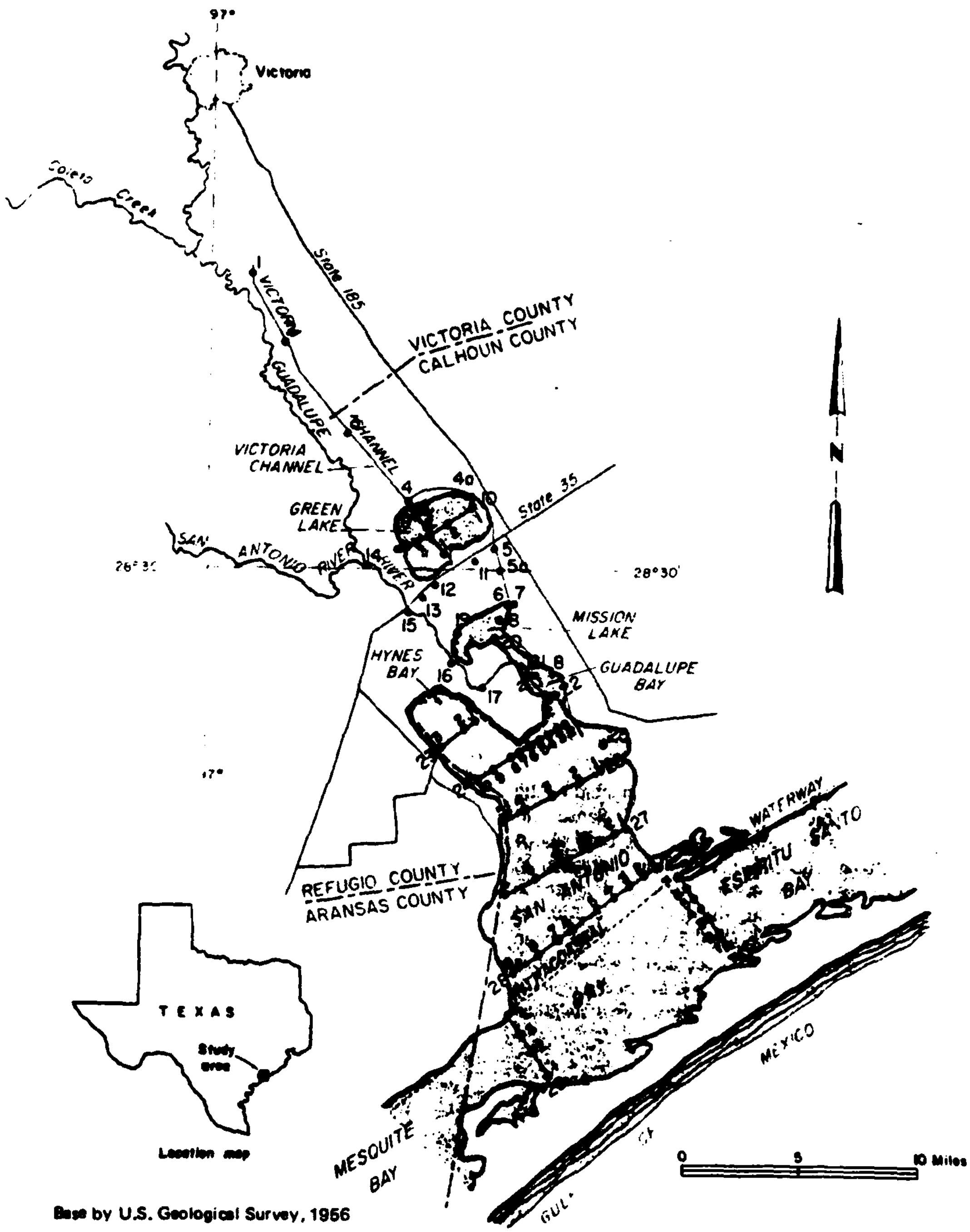
a. Summary

San Antonio Bay is the largest and most important part of the estuarine system formed by the Guadalupe River just after it receives the San Antonio River (Figure A-14). The total estuary covers upwards of 150 square miles (96,000 acres) of which San Antonio Bay accounts for 132 square miles or 84,480 acres. Approximately 30,000 acres of the embayment shore consist of salt flats and marshy lands. Matagorda Island, which is rather well vegetated, separates San Antonio Bay from the Gulf. San Antonio Bay does not have a truly direct connection with the Gulf of Mexico. To the northeast it connects with Espiritu Santo Bay and thence to the Gulf via Pass Cavallo; to the southeast it connects with Mesquite Bay and Aransas Bay and thence to the Gulf via Aransas Pass.

The Guadalupe River, including its tributaries, drains about 10,400 square miles and annually discharges about 1.5 million acre-feet of fresh water into the Bay. Sediment inflow to the Bay is substantial, amounting to about 1.6 million tons of silt per year.

The principal sediments of the Bay are silts and clays around the Guadalupe delta; shell material confined to patches in the bay center; sandy sediments and clays to the southwest where washover may be important.

The climate in the estuary is semi-tropical and fits the criteria for the dry subhumid zone. Thus even though the annual precipitation averages 38 inches over



Base by U.S. Geological Survey, 1956

Numbers represent water sample collection sites of Hahl and Ratzlaff 1970,1972.

FIGURE A–14 SAN ANTONIO BAY

the estuary, evaporation exceeds this by about 12 inches per year, creating a water-deficit habitat. The average annual air temperature is approximately 70°F. Prevailing winds are southeasterly with an average of about 11.4 mph. The estuary is subject to high winds from "northers" and hurricanes. A hurricane passed directly across San Antonio Bay in 1934 and winds up to 111 mph were clocked on the east shore.

San Antonio Bay is probably the least spoiled of the Texas embayments. Nevertheless, it is not now as important a contributor of seafood products to the Texas economy as might be expected. The dollar value of the seafood harvested in its waters ranks it fourth in the state of Texas. Its oyster production is third highest in the state, but it falls to fourth place for shrimp landings, fifth place for crabs, and sixth for finfish. Its importance as a nursery ground cannot be overemphasized.

This estuary, too, is important as a wintering area for various types of migratory birds. About half of the shoreline of the Aransas National Wildlife Refuge borders the San Antonio estuary, which includes Mesquite Bay. Here, again, a major part of the winter habitat for the whooping crane is located in this area.

San Antonio Bay area is the least disturbed estuarine complex in Texas today. For this reason it provides a very important nursery ground for various species of fishes and crustaceans. In this sense, it is extremely vulnerable to pollutants that would enter the estuary via Pass Cavallo. The second biological entity sensitive to possible environmental perturbations associated with oil terminals would be that part of the Aransas National Wildlife Refuge on Black Jack Peninsula, which forms part of the shore of San Antonio Bay.

b. Physical Characteristics

(1) Hydrology

(a) Physiographic. – The Guadalupe River estuarine complex consists of the tidal parts of the Guadalupe River, Mission Lake, Guadalupe Bay, Hynes Bay, San Antonio Bay, Victoria Channel, and parts of the Intracoastal Waterway. For present purposes San Antonio Bay is the most important part of the system. At its upper end it receives fresh water from the Guadalupe River just after it has received the San Antonio River. The expanded lower end of the Bay abuts against Matagorda Island, and at either end of the island the Bay is connected to the Gulf through a complicated system of bays and passes. Thus, to the northeast, it joins Espiritu Santo Bay and eventually the Gulf of Mexico through Pass Cavallo that lies at the entrance of Lavaca Bay. To the southwest San Antonio Bay joins Mesquite Bay that, in turn joins Aransas Bay, which finally connects with the Gulf through Aransas Pass. Although small, Mesquite Bay is connected directly with the Gulf through the very narrow Cedar Bayou Pass. The Guadalupe Estuary has a combined area of about 150 square miles. San Antonio Bay alone accounts for about 132 square miles of this total and has a shoreline of about 92 miles. Its maximum depth is about 8 feet, but depths over 6 feet are rare, and the mean depth is 4 feet above mlw. At

mlw, the Guadalupe River is about 10 feet deep; Mission Lake, Guadalupe Bay, and Hynes Bay are less than 3 feet deep; Victoria Channel is more than 8 feet deep; and the Intracoastal Waterway is about 15 feet deep (Hahl and Ratzlaff, 1972).

The bottom of San Antonio Bay is quite regular, the only significant irregularities being oyster reefs. These are most numerous in the central part of the bay where they may breach the surface at low tide. Also, where the bay is traversed by the Waterway, spoil banks form small islands at low water.

The Guadalupe estuarine complex is located in the dry subhumid climatic zone (Figure A-4). Thus even though its rainfall averages about 38 inches per year (Figure A-2) with the wettest season coinciding with the cooler months, evaporation exceeds rainfall by about 12 inches per year (Figure A-3). The Guadalupe River, including its tributaries, drains an area of about 10,400 square miles and annually discharges about 1.5 million acre-feet of fresh water into the Bay along with 1.6 million tons of silt. In spite of substantial rainfall and river input of fresh water, this is a water deficit area, as mentioned previously.

(b) Salinity. – The salinity of San Antonio Bay waters ranges from near 4°/oo at the northern end to about 25°/oo at the southern end. Extreme ranges given by Hahl and Ratzlaff (1972) are from 0 to 27°/oo in 1969. Substantial variations do occur on both periodic and seasonal bases, depending primarily on flow from the Guadalupe River.

(c) Temperature. – Surface water temperature in the center of San Antonio Bay ordinarily ranges from about 8.3°C in January to 32.5°C in August (Hahl and Ratzlaff, 1972).

(d) Tides. – Because the Guadalupe estuary is connected to the Gulf of Mexico indirectly through Espiritu Santo and Mesquite Bays, tidal stages average only about half a foot. Wind tides of as much as four feet are common in the bay, and they may rise very rapidly. Also, stage changes caused by increases in stream flow are at times considerably greater than those caused by astronomic tides. For instance, Hahl and Ratzlaff (1972) report that the surface elevation of San Antonio Bay in November (1969) averaged 0.5 feet above mean sea level, and that measured inflow to the bay for the weeks preceding the survey average 1147 cubic feet per second. A follow-up survey in April 1970 showed the average to be 1.4 feet above mean sea level, and that the measured inflow averaged 13,950 cfs.

(e) Currents. – Disregarding the influence of strong winds, currents in San Antonio and adjacent bays differ with tidal state. Childress (1961 Job Report) has shown that during periods of incoming tides, Gulf water enters Pass Cavallo and some of it flows westward through Espiritu Santo Bay and turns northward to flow along the eastern part of San Antonio Bay. Water exits along the western shore and flows into Mesquite Bay to the west. During ebb tide water leaving San Antonio Bay flows both east and west, moving eventually into the Gulf again via Pass Cavallo, Cedar Bayou, and Aransas Pass.

(f) Winds. – The prevailing winds over the Guadalupe complex are southeasterly and south by southeast. These average about 11.4 mph with a monthly range of averages from 9.6 to 13.8 mph. Peak winds have ranged up to 111 mph during hurricane passage in the vicinity (Brower et al., 1972). High winds associated with passage of hurricanes can be expected about every 3 to 4 years on average (Figure A-5).

(2) Geology

The bottom of San Antonio Bay between oyster reefs is composed of shell, sand, silts, and clays. The barrier island (Matagorda) contributes some sediment to the southern part of the bay from wind action, but this component is not as important here as in the Laguna Madre, because the northern portion of the island is marshy. Thus, the marsh vegetation prevents the movement of the sand derived from dunes farther south on the island. Shepard and Moore (1960) found that most of the sand in the Bay was derived from (1) the Gulf via Cedar Bayou inlet, and (2) from Espiritu Santo Bay through transport of swift currents created by strong north winds (65 mph) of winter. Childress (1961) and Shepard and Moore (1960) describe the distribution of bottom sediments as follows:

(1) shell material is confined to patches in the bay center:

(2) silts and clays are dominant around the Guadalupe River delta;

(3) a tongue of these fine sediments extends down the center and east side of the bay, carried by the current of low-salinity water;

(4) very sandy sediments mixed with clays are found in Mesquite Bay to the southwest where the effects of the inlet (Cedar Bayou) and washover are important.

(5) sediments near the delta and the mouths of the present streams have a rather high content of wood debris – here, also, sediments tend to be laminated, whereas down the bay they are not. This situation probably results from lack of marine benthic animal activity in low-salinity water of the delta.

(3) Chemistry

Hahl and Ratzlaff (1972) give the following values (extremes) for some important chemical parameters averaged from samples taken from various stations on San Antonio Bay. Unless otherwise stated, values are given in mg per liter.

pH	7.3-8.8
Dissolved O_2 (ml/l)	5.3-12.2
BOD	0.4-8.3
SiO_2	3.7-13.0
NO_3	0.0-0.2
NH_4	0.0-0.05
NO_2	0.01-0.02
PO_4	
ortho	0.01-0.20
Total	0.04-0.36
DOC mg/Cl	3.3-4.0

c. Resident and Transient Marine Biota

(1) Attached Plants

Key Species. – The very shallow-tertiary bays and "lakes" forming the margins of San Antonio Bay range in depth from about two feet up to tidal marshes. These marshes support profuse vegetational growth of the species common to the whole area (*Spartina, Diplanthera, Salicornia,* etc.). These marshes provide much food and protection to the young of many species of marine animals, including all of those of commercial importance except the oyster.

(2) Zoobenthos

Key Species. – The most important species of invertebrate animals in San Antonio Bay are the white shrimp (*Penaeus setiferus*), the brown shrimp (*Penaeus aztecus*), and the oyster (*Crassostrea virginica*).

Childress (1961) feels that the two most important environmental factors influencing shrimp production in San Antonio Bay are the Gulf of Mexico tides and the fluctuating flow of the Guadalupe River. This combination of tides and river flow causes changes in available food and affects salinities adversely. Some of these changes can also be modified on a small time scale by winds.

Essentially the same constraints are placed upon oyster development by river flow and tides. Periodically an unusual high influx of fresh water kills most of the oyster reefs in San Antonio Bay. This is particularly true of reefs near the river delta. On the other hand, Childress (1961) found that oyster production levels are much more stable in the adjacent Espiritu Santo Bay, which is very much cut off from the flow of the river and thus maintains salinities high enough to sustain production. Also, the harder bottom conditions in this latter bay are more suitable for the settlement of oyster spat.

It appears that both species of shrimp prefer the less saline waters (5-12°/oo) of upper San Antonio Bay as their nursery grounds. After they reach 10 cm length, they slowly start migrating to the more saline waters of the lower bay areas, and

finally enter the Gulf of Mexico. Juvenile shrimp appear in the bay in early April. They grow about 1.5 mm per day (Moffett, 1966). Shrimp begin to leave the bay in June and continue the exodus well into July.

Approximately 10,000 acres of oyster reefs are found in San Antonio and the adjacent Espiritu Santo bays.

Some of the invertebrate animals associated with the oyster reefs in their bays were provided by Childress (1961), as follows:

Cliona sp. Boring sponge
Membranipora sp. and *Bugula* sp. Ectoprocts
The bivalves – *Brachiodontes exustus* and *Martesia smithii*
The annelids – *Polydora* sp. and *Dexiospira*
The hermit crab – *Pagurus floridanus*
Blue crab – *Callinectes sapidus*
Other crabs – *Panopeus herbstii*, *Eurypanopeus depressus*, and *Menippe mercenaria*

(3) Pelagic Fauna

Ichthyofauna. – A wide variety of fishes occur in San Antonio and adjacent bays. This bay, however, does not support a very important finfishery within its waters. It is much more important as a nursery for Gulf fishes. The three most important species to the bay's commercial fishery are the Redfish *(Sciaenops ocellata)*, Black Drum *(Pogonias cromis)*; and Spotted Sea Trout *(Cynoscion nebulosus)*. Some of the important forage fishes (that is fishes used as food by game fishes) are Spot *(Leiostomus xanthurus)*, Atlantic Croaker *(Micropogon undulatus)*, and Pinfish *(Lagodon rhomboides)*.

4. Matagorda Bays

a. Summary

The most important components of the estuary of the Lavaca and Navidad Rivers are Matagorda Bay, Lavaca Bay, and East Matagorda Bay (Figure A-15). The entire estuarine complex covers about 224,000 acres. The estuary is separated from the Gulf of Mexico by Matagorda Peninsula which is breached near its midpoint by the Colorado River that once emptied into the estuary but now flows to the Gulf. One major entrance to the estuary is Pass Cavallo at the south end of Matagorda Bay; the other entrance is the Matagorda Ship Channel, which is located a few miles northeast of the Pass.

The Lavaca River and its tributary, the Navidad River, supply a runoff of approximately 600,000 acre-feet annually to the estuary via Lavaca Bay. Salinity concentrations in the estuary average about 20 parts per thousand, but, as in other bays, these values vary greatly with position in the estuary and amount of rainfall in the watershed.

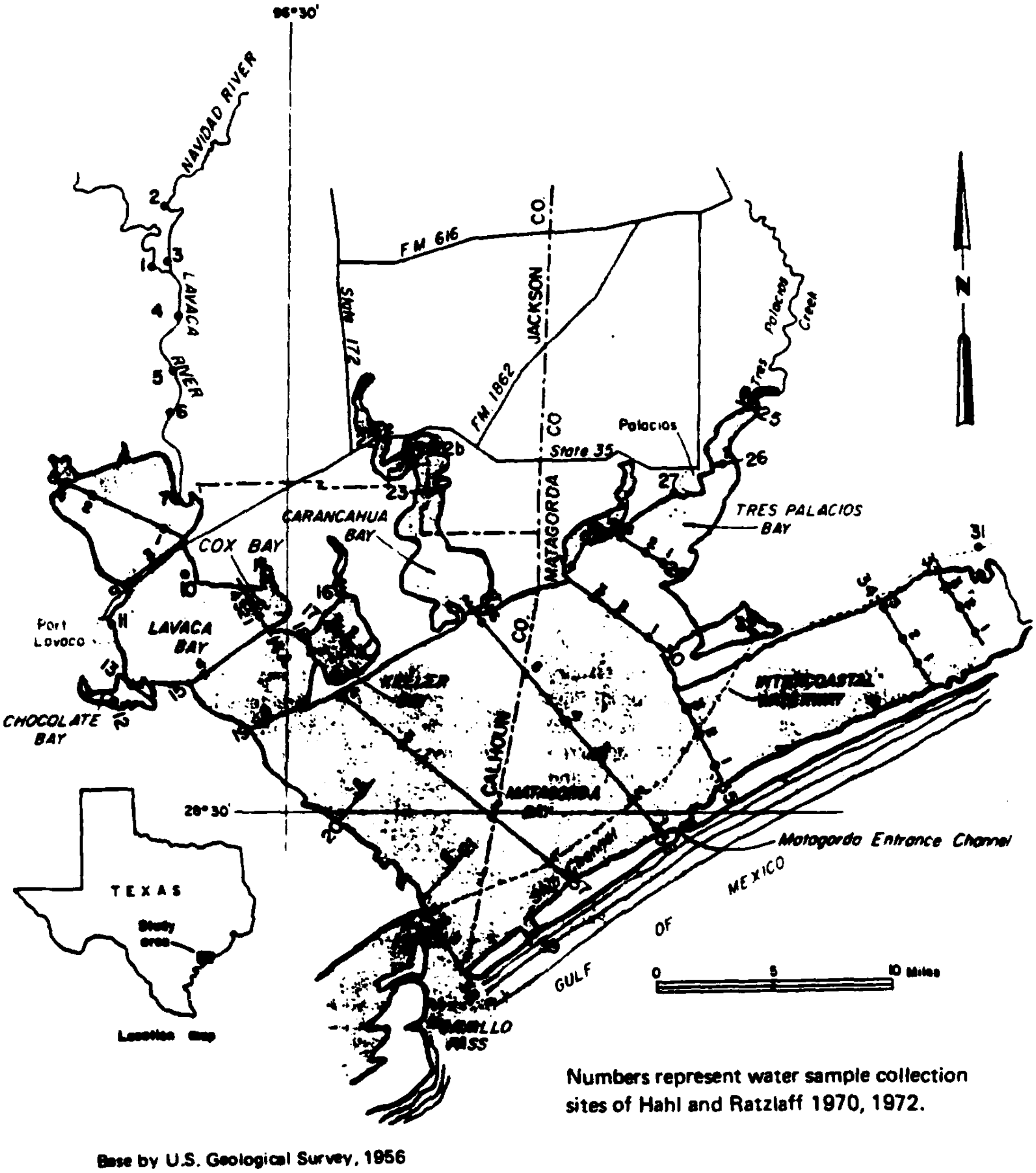


FIGURE A–15 MATAGORDA BAY

Matagorda Bay lies in the wet subhumid climatic zone and enjoys semi-tropical conditions. The annual precipitation averages about 38.7 inches, but evaporation exceeds this by about 4 inches per year. The annual average air temperature over the estuary is 69.2°F. The mean maximum air temperature is 90°F (July) and the mean minimum air temperature at Matagorda, Texas is 48°F (Jan.). Prevailing winds are southeasterly with an average velocity of about 10.2 mph. Hurricanes with winds up to 135 mph have been reported over the estuary in 1934, 1941, 1942, 1945, and 1961. During passage of Hurricane *Carla* in September 1961, tides of 18.5 feet were reported in Port Lavaca. Normal astronomic tides are diurnal and average about 1.0 foot over the estuary.

This estuary is the second most important producer of seafood products in Texas. In 1970, it came second in oyster meat and shrimp production and third in crab and finfish production.

Although important as a wintering and breeding ground for many species of waterfowl, the Matagorda estuary cannot be considered as valuable as the region around the Aransas Wildlife Refuge.

b. Physical Characteristics

(1) Hydrology

(a) Physiographic. – The Lavaca-Tres Palacios estuary is composed of Matagorda Bay, East Matagorda Bay, Lavaca Bay, and Tres Palacios Bay. This complex, including the several secondary bays, covers more than 224,000 acres (Hahl and Ratzlaff, 1970). Matagorda Bay is separated from the Gulf of Mexico by the long, narrow barrier beach, Matagorda Peninsula. Pass Cavallo, the major inlet, is situated at the southwestern end of the peninsula and has a maximum depth of 42 feet. This natural pass is about 1.8 miles wide and has maintained its present position for 200 years (Simmons and Rhodes, 1966). Green's Bayou, another Gulf inlet to the estuary, maintains a depth of approximately six feet (Fagg, 1957).

Prior to 1936 the Colorado River emptied into East Matagorda Bay, slowly forming a delta across the bay. With completion of the delta and direct flow of the Colorado River into the Gulf, the Lavaca River remained as the only major stream supplying fresh water to the estuary. The Lavaca and its tributary, the Navidad River, supply a runoff of approximately 600,000 acre-feet yearly (Texas Almanac, 1972). This volume actually empties into the shallow Lavaca Bay (depth of 6 to 7 feet).

This estuarine complex is located in the wet subhumid belt as shown by Thornthwaite (1948). The Texas Almanac (1972) lists Matagorda County as receiving 40.85 inches of rainfall annually. Fisher et al. (1972) show that the average annual rainfall minus average potential evapotranspiration is equal to -2 to -10 inches.

The shoreline of Matagorda Bay is characterized by narrow beaches, in most cases less than 10 feet wide, backed by a cliff usually 5 to 8 feet in height. The barrier island is generally less than 5 to 10 feet in elevation.

The floor of the bay is rather featureless and reaches a maximum depth of 14.5 feet (prevalent depth range from 11 to 12 feet). These figures refer to Matagorda Bay with depths in East Matagorda ranging from 2 to 10 feet and showing a definite shallowing east of the delta area (Shepard and Moore, 1960). The Matagorda Ship Channel is maintained at more than 40 feet.

(b) Salinity. – The annual salinity distribution of the estuary is the product of precipitation and runoff during the winter and spring, and evaporation during the rest of the year. Data taken from Hahl and Ratzlaff (1972) show a salinity range of 12 to 26°/oo for East Matagorda Bay, 10 to 28°/oo for Matagorda Bay proper, and 4 to 26°/oo in upper Matagorda Bay. It is assumed that the latter bay area would be similar to Lavaca Bay. The Coastal Fisheries Report (1966) gives average monthly salinities for the Matagorda area. A minimum of 10.9°/oo was recorded for May with December having the maximum of 25.0°/oo. In 1967, the range was from 13.9°/oo in October to 28.4°/oo in July. The amount of rainfall during the month tends to be reflected in the average salinity for that month. For instance, in the wet year of 1966 the average salinity over all stations in Matagorda Bay was 16.9°/oo, whereas in the dry year 1967 the average climbed to 23.8°/oo.

(c) Temperature. – The average monthly water temperature ranged from 12.9°C in January to 30.2°C in July during 1966. In 1967, a maximum of 30.2°C was noted in June while the minimum (14.3°C) occurred in February. Shenton (1957) gives temperature data showing a conformable range of 10°C-31°C for one report period and 8°C to 30.5°C for another period. The 8°C reading was taken during a severe norther during the month of March 1955.

(d) Tides. – The mean diurnal tide range of Matagorda Bay and connecting arms is about 0.7 feet (Simmons and Rhodes, 1966). Astronomic tides are considerably affected by winds and atmospheric conditions, causing water-surface elevations to vary. During prolonged north winds the surface can be two feet below mean low tide (one foot below mean sea level) as compared to 15 feet above mean low tide during tropical hurricanes.

(e) Winds. – Brower, et al., (1972) gives data for the Victoria, Texas area which is in the immediate vicinity of Matagorda Bay. These data are very similar to those for both the Galveston and Corpus Christi areas (given elsewhere in this report). The mean speed for the year was listed as approximately 10.2 mph from a predominantly southeastern direction. The maximum recorded wind over the estuary was 175 mph with passage of a hurricane in 1961.

(f) Currents. – The Lavaca-Tres Palacios estuary has currents that tend to be typical of most bay systems. These currents are associated with winds, waves, tides and salinity fluctuations. It should be pointed out that data on file with the

Department of Oceanography at Texas A&M University indicate that under normal conditions there is little or no current activity in the bay (Shenton, 1957).

(g) Storms. – Breaches in Matagorda Peninsula by storm action, such as those caused by *Carla*, increase the tides and the mean salinity of the estuary. These breaks would have only temporary effect due to soon being closed by littoral action. Carr (1967) shows this estuary as having received the effects of 20 hurricanes between 1900-1956.

Rainstorms in the Colorado River drainage area can cause flooding over the delta area thus allowing an appreciable volume of fresh water to enter Matagorda Bay. Such an occurrence was seen in 1969 when more than 8.5 inches fell within a 24 hour period. Snow or ice has been recorded on only four occasions (in trace amounts) since 1948 (Brower, et al., 1972). The record lowest temperature was 16°F in January 1962.

(2) Geology

(a) Barrier Island Complex. – Matagorda Peninsula is characterized by a wide flat beach and low sand dunes along the Gulf coast. In general the outer shoreline is almost straight. Cusps that might have formed due to storm action are temporary since they will probably be smoothed out with the passage of the next storm. The beach is fine sand and slopes very gently upward to a point where wiregrass *(Spartina patens)* begins its growth. This plant is dominant among the flora on the beach ridge.

The inner shoreline is irregular and shows numerous spits and wash-over fans (Andrews, 1971). It is characterized by narrow beaches that are littered with driftwood that has floated down the Colorado River. The beaches are backed by a cliff, slightly lower than the overall elevation of the barrier island.

(b) Lagoon-Bay Complex. – The surface of the bottom deposits in Matagorda Bay consists of various combinations of sand, silt, and clay with some shell. The principal sediment type is a moderately sorted silty clay. In general, the deposits grade from coarse to fine as the distance increases from shore.

The sorting in the sand sizes range from very good to poor. This is apparently attributed to the large amounts of shell in the poorly sorted samples. In the finer sediments, the sorting has a tendency to be poor to very poor (Shenton, 1957).

The western side of the bay consists mostly of sand close to shore, with silty sand and finally silty clay toward the center of the bay. The mouth of Pass Cavallo is principally sand, with some sand-silt-clay with shell. A small area of sand extends along the northwestern shore of Matagorda Peninsula. The northern shore has a belt of sand-silt-clay with shell which is close to the remains of Halfmoon Reef (oyster).

In the vicinity of the reef, there are several sediment types with the variation probably due to the proximity of the reef. The coarser sediments in this region may be due, in part, to the reworking of reef deposits.

It seems likely that, on the west side of the bay, there has been much reworking of the older deposits during hurricanes. Some portions of the shoreline have had considerable erosion during the last few decades (Shenton, 1957). This may account for some of the sand patches in this area. It is noted that off the western shore the sediments progress generally from a sand to a silty sand and a silty clay toward the center of the bay.

(3) Chemistry

The following values for chemical parameters were compiled from Hahl and Ratzlaff (1972). The values for dissolved organic carbon (DOC) are given by Maurer and Parker (1972).

Values mg/l or as Given	East Matagorda (Ranges)	Matagorda (Ranges)	Upper Matagorda (Ranges)
pH	8.3-8.5	7.1-8.8	6.9-8.5
O_2 (ml/l)	4.3-6.0	0.2-10.6	0-12.1
BOD	0.8-2.3	1.1-4.8	0.3-7.5
SiO_2	0.6-6.2	0.2-5.3	0-12
NO_3	0.0-0.1	0.0-0.2	0-0.4
NH_4	trace	trace	trace
NO_2	trace	trace	trace
Phosphate			
Orthophosphate as phosphorus	0.01-0.05	0.00-0.04	0.01-0.20
Total phosphorus	0.03-0.08	0.01-0.07	0.2-0.21
Secchi Disk (cm)	33-69	43-137	18-109
DOC	no data	3.6-4.2	4.6-4.9

c. Resident and Transient Marine Biota

(1) Attached Vegetation

The salt marsh found on the back of the barrier island and along the delta formed by the Colorado River is somewhat limited in extent due to the low tidal fluctuation within Matagorda Bay. This area contains plants such as cordgrass *(Spartina alterniflora)*, grasswort *(Salicornia perennis)*, saltwort *(Batis maritima)*, seepweed *(Suaeda* sp.), and sea oxeye *(Borrichia frutescens)*, inland from the shoreline to higher marsh areas, respectively (Fisher, et al., 1971).

The marginal areas, where sand predominates as sediment, support the marine grasses *Thalassia*, *Ruppia*, and *Diplanthera*. The calcareous green alga, *Acetabularia* is found in these areas.

(2) Zoobenthos

Job Reports by Day (1960) on file with the Texas Game and Fish Commission represent a fairly thorough study of the Matagorda Bay area. The brown shrimp *(Penaeus aztecus)* was found present in the area from mid-April through mid-December with peak abundance from mid-April through mid-July. Two spawning peaks for this species were noted in the estuary. Migrations of the brown shrimp from the bay area into the open Gulf occurred during June and July. *Penaeus setiferus* (white shrimp) show a spring migration from the Gulf to the north shore of Matagorda Bay during the middle of April. The greatest abundance was in May and the mid-June return migration to the Gulf occurred simultaneously with that of the brown shrimp. A second spawning peak for the white shrimp was indicated by their increase in numbers during late fall. The major portion of the shrimp population had moved out of the Matagorda Bay area by the middle of December. Data taken from Texas Landings (1971) indicate that the shrimp industry is most important for this estuarine complex. The previously mentioned species, coupled with bait-type shrimp, were caught in excess of 2,000,000 pounds (value $74,000) during 1970.

The blue crab *(Callinectes sapidus)* shows greatest abundance during the months from March through October. The importance of the Matagorda Bay as a nursery is implied by the great number of ovigerous females from April to July. The larger crabs (124mm+) left the area during October with only a few taken from deep water during the winter.

The oyster, *Crassostrea virginica*, is found as dense reefs only in a few areas – Turtle Bay, Oyster Lake, and smaller ones in Lavaca Bay. Scattered small patches are noted on the eastern end of the bay. Even with their restricted distribution, oysters taken from Matagorda rank second in number only to Galveston. The dollar value of 479,500 pounds taken in 1970 was $183,322. A similar reef fauna to that listed specifically for the Galveston Bay area would be found in conjunction with the oyster reefs of this bay area.

Areas of heavy bryozoan *(Bugula)* growth are used as nursery grounds by both the white and brown shrimp. Furthermore, the bryozoan has been noted in the foreguts of white shrimp. A total of 44 invertebrate species has been collected and identified from the area.

(3) Pelagic Fauna

Zooplankton. – No data available. It is suspected that the larvae of some of the invertebrate forms referred to under Zoobenthos would be found as components of the Zooplankton.

Ichthyofauna. – Coastal Fisheries Project Reports (Day, 1963 and King, 1960) reveal that most of the important commercial, sports, and forage fishes are found within Matagorda Bay. The speckled trout *(Cynoscion nebulosus)* had zero age class fish first taken during late May with spawned out trout appearing by late July. Zero

age class fish are normally first taken in January for flounder *(Paralichthys lethostigma)* and redfish *(Sciaenops ocellata)*. The dominant species in the forage samples tend to be *Anchoa mitchelli* (anchovy) and *Micropogon undulatus* (croaker). Black drum *(Pogonias cromis)*, sheepshead *(Archosargus probatocephalus)* and sand trout *(Cynoscion arenarius)* are also taken in abundance.

Matagorda Bay ranks in third position for production of finfish from the commercial standpoint. Texas Landings (1972) lists it at 457,000 pounds (value $80,000), following the Lower and Upper Laguna Madre in total catch.

(4) Bioproductivity

Matagorda Bay ranks second among the Texas bays in production ($1,074,475) of combined shellfish and finfishes.

5. Trinity River Estuary (Galveston Bay)

a. Summary

The Trinity River estuary with a total area of about 804,000 acres, of which 354,000 are water, is by far the largest embayment on the Texas Coast. Its principal components are the tidal portions of the San Jacinto and Trinity Rivers, Trinity Bay, Galveston Bay (Upper and Lower), East Bay, and the West Bay (Figure A-16). In this report the Houston Ship Channel, which serves the Port of Houston, is also considered as an integral part of the estuarine complex.

By most criteria the Galveston embayments and channels comprise the leading waterway of Texas. It serves the largest metropolis in the State (Houston, about 2 million population) and handles 44 percent of the total cargo tonnage exchanged by Texas ports. The largest oil refinery complex in the coastal zone is found here. In addition it supports the State's largest recreational and tourist centers.

Located at the transition between wet subhumid and humid climatic zones, Galveston's average annual precipitation of about 46 inches exceeds evapotranspiration by at least 6 inches. The weather is semi-tropical with the mean maximum July temperature being 30.5°C and the mean January temperature dropping to 9.5°C.

The overall salinity in the estuary ranges between 10°/oo and 30°/oo with an average of about 12°/oo. The salinity range varies from place to place in the estuary, being only 10-16°/oo in Trinity Bay and 24-30°/oo in West Bay. At times of peak river inflow surface salinities drop rapidly in Trinity and Upper Galveston Bays, but not in West Bay. In drier parts of the year, a high-salinity wedge may penetrate far into Galveston Bay via Bolivar Roads Pass and the Houston Ship Channel.

In any given year the surface water temperature of the central body of the estuary can be expected to have a range of about 28°C (from ca. 5° to 33°C). In an average season temperatures rise steadily from lows in January to a high in

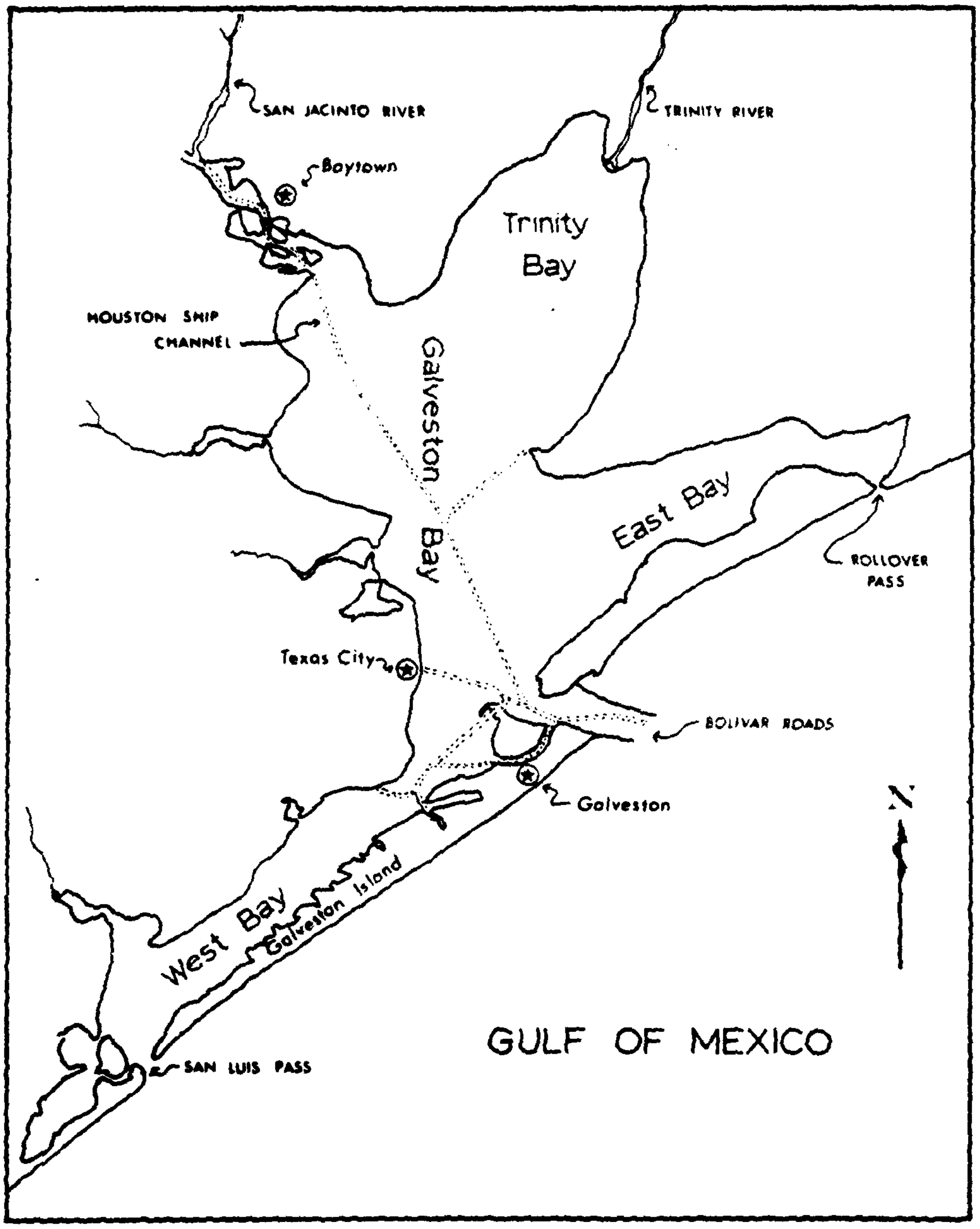


FIGURE A–16 GALVESTON BAY

July-August. Temperatures can be expected to fluctuate considerably in fall and early winter – a phenomenon probably associated with the passage of cold fronts during this time.

Tidal exchange together with river inflow are reasonably effective agents of flushing in the main parts of the estuary. The diurnal tides have an average range of about 1.25 feet, whereas the semi-diurnal component measures only about 0.5 foot. Flood and ebb currents in Houston Ship Channel are on the order of a knot. Tidal currents in Bolivar Roads Pass, which handles about 85% of the exchange between Gulf and estuary, range between 3.3 knots (flood tide) and 4.3 knots during peak of ebb flow.

The prevailing winds here are moderate southeasterlies, averaging about 11 mph, but high velocity winds are not uncommon. The greatest frequency of winds with speed greater than 45 mph occurs in December. But the highest velocity winds (up to 118 mph) are recorded in summer and fall, and are associated with hurricanes. The latter may affect the area as often as every 3-4 years on average. The last severe storm that struck the area was in 1961 when a tornado spawned by Hurricane *Carla* (the largest hurricane of record) ripped through Galveston.

Submerged aquatic vegetation is practically non-existent in the turbid waters east of the Galveston Causeway. Most of the emergent marsh vegetation is found in East and West Bays and on the Trinity River delta.

The key benthic invertebrate animals include the oyster *(Crassostrea virginica)*, which forms reefs covering a total of 14,700 acres in the complex. Some of the individual reefs cover tens of acres. Two other species of paramount importance are the brown and white shrimp. Although many species of fish are found in Galveston Bay, the finfishery is of secondary importance to shellfish fishery at the present time.

In view of the great commercial and industrial development found there, it is a source of surprise that in 1970 Galveston and Trinity Bays produced 12.101,300 pounds of shellfish, worth $3,920,000 at the dock. It thus leads the state in oyster, bay shrimp, and crab production. In fact, its shellfish catch exceeds that of all the other bays of Texas combined. It does not, however, have a large finfishery, ranking 5th behind the two Laguna Madres, Matagorda Bay, and Aransas Bay.

The Galveston estuarine complex is preeminently important as a wintering habitat for various species of waterfowl. The 1972 midwinter waterfowl survey of the Texas coast conducted by the Texas Parks and Wildlife Department shows that 90% of the ducks, 93% of the geese, and 86% of the coots winter in Texas from the Louisiana border to Matagorda Bay. The total involved is over 2,218,000 waterfowl, and it is estimated that 186 million waterfowl days are expended in the Galveston embayment and environs.

The importance of the Trinity estuary as a producer of biological products has been established. Its remarkable capability of retaining this capacity in view of major industrial developments and concomitant increases in dangerous pollutants is based in part on the flushing brought about by large fresh water inflow and the orientation and size of Bolivar Roads Pass.

It is obvious that every thoughtful effort should be made to not only not increase the pollution of the estuary but to actually accelerate its reduction. This does not necessarily mean that further industrial development should not be permitted. It does mean that more intelligent methods of disposing of all dangerous wastes must be employed.

If an offshore terminal is to be constructed in the vicinity of this estuary, careful planning will see to it that the specific construction site is so located that petroleum spills of any considerable size will not be carried to Bolivar Roads Pass under average circumstances of wind, tide, and current. Sufficient data are presented in this report to identify good and bad locations in the context of the problem at hand.

b. Physical Characteristics

(1) Hydrology

(a) Physiographic. – The Galveston Bay estuary comprises an area of about 803,600 acres and includes Trinity, Upper Galveston, Lower Galveston, East, and West Bays. These primary bays are bounded by numerous secondary ones, with interconnecting tertiary bays, that offer additional fresh water to the estuary's major source from the Trinity and San Jacinto Rivers. Numerous islands, most being formed from spoil, are found throughout the estuarine complex which has about 300 miles of shoreline and a water surface area of 353,920 acres (Fisher, et al., 1972). Water depth in the bays ranges from 2 to 12 feet, the latter being characteristic of the Gulf Intracoastal Waterway that traverses the estuary in an east-west direction.

The estuary, protected from the Gulf of Mexico by barrier islands, is connected to the open marine waters by three passes that permit an interchange of waters. The largest pass, a natural one, is Bolivar Roads which has a width of about 9000 feet and an average depth of 20 feet (modified by construction of a deep draft channel connecting with those to Galveston, Texas City, and Houston). San Luis Pass, the other natural one, is about 3000 feet wide with an average depth of only 4 to 5 feet. The only man-made pass, Rollover, varies in width from 50 to 200 feet and is shallow in depth. Bernard, et al. (1959) show the current in Bolivar Roads as reaching 3.3 knots during flood and 4.3 knots on ebb tide.

Galveston Bay estuary is situated in the region of transition from the wet subhumid climatic belt to the humid belt (Thornthwaite, 1948). The weather is essentially semi-tropical with the mean maximum July temperature being 87°F

(30.5°C) and the mean January temperature as 49°F (9.5°C) (Brower et al., 1972). The estuary receives between 42-48 inches of rainfall with an average of about 9.1 million acre-feet of fresh water inflow annually (Fisher et al., 1972). The San Jacinto and Trinity Rivers, with respective runoffs of 2 million and 5.8 million acre-feet, account for the bulk of this fresh water (Texas Almanac, 1972). Turbidity of the bay waters tends to parallel the amount of inflow and rainfall, with that portion of the system east of the Galveston Causeway often being muddy.

As previously stated, the Galveston Bay estuary has a moderate amount of shoreline that appears quite regular. It is relatively flat and rises gradually from the bay bottoms. Erosion has affected some areas, forming a low bluff, but the greatest modification of the shoreline has been due to man's development. Due to an increase of these activities in recent years it appears that the shoreline of the entire estuary is in danger of being developed.

Modification of the estuarine environment of this area has resulted from such activities as: (1) dredging and deposition of spoil related to construction and maintenance of navigation channels, (2) dredging of oyster shell and fill material, (3) construction of hurricane protection levees, (4) pollution by man and industry. These activities tend to parallel the fact that the Galveston Bay complex is the largest and one of the most important estuarine systems, both economically and ecologically, of all the bays on the Texas coast (Copeland and Fruh, 1970).

(b) Salinity. – The Galveston Bay system is essentially nonstratified except in the channels where differences in salinity at the surface and near the bottom may be as large at 15°/oo. The average salinity of the estuary is about 12°/oo but an examination of isohalines indicates a tongue of Gulf water, 36.6°/oo, extending a considerable distance up the Houston Ship Channel (Copeland and Fruh, 1970). Salinity concentrations in the estuary are inverse to the amount of fresh water inflow into the bays. The lower salinity concentrations are near the freshwater sources while the higher salinities are near the Gulf passes.

The areal distribution of average salinities for a four year period show that they increase from east to west and north to south in the estuary (Pullen et al., 1971). Configurations of the isohalines in the western portion of the system emphasize the importance of Bolivar Roads Pass and the Houston Ship Channel as an area for exchange of bay and Gulf Waters. Rollover Pass has little effect on salinity except in the immediate vicinity of the pass.

The average salinity range for each of the individual bays of the estuary may be noted in the table shown in the section on chemistry. As with other estuaries in the Gulf of Mexico, the Galveston Bay estuary is subject to freshening following hurricanes and during fresh water inflows.

(c) Temperatures. – Pullen, et al. (1971) showed the water temperature during a four year study to range from 0.4°C to 36.0°C. The smallest annual range was 23.4°C (9.0°-32.4°) and the largest was 33.6° (0.4°-34.0°). The expected large

temperature difference between the shallow open-water and the deeper ship-channel was not observed. It was felt that passage of large ships through the channel caused mixing of the surface and bottom waters, thus giving rise to similar water temperatures.

The average seasonal trend revealed lowest temperatures in January with a monthly increase through July, which had a mean temperature of 30°C. Temperatures fluctuated over a greater range in the fall and winter, probably due to passage of cold fronts during this time. A sharp decrease in temperature was noted from November to December. The temperature difference between the primary bays of the estuary was only approximately 1°C.

(d) Tides. – Tidal exchange accounts for flushing of the estuary, chiefly through Bolivar Roads. There are two types of tides in the bay, a diurnal tide which has an average range of about 1.25 feet and a semi-diurnal tide of about 0.5 foot (Copeland and Fruh, 1970). Flood and ebb currents in the Houston Ship Channel are on the order of 1 knot while in the shallower areas of the bay these currents are about 0.2 knot. They can reach up to 2.5 knots in some of the channels between reefs.

Wind generated waves frequently negate tidal influence because of the shallowness of the bay. Prevailing south and southeast winds may raise the level of the bay two to three feet while winds from the north, during passage of cold fronts, have lowered the bay level as much as four feet. This lowering temporarily exposes the shallow bay bottom to subaerial conditions (Lankford and Rogers, 1969).

Water is exchanged with the Gulf of Mexico through the three previously mentioned passes. About 85% of this exchange is through Bolivar Roads, 14% through San Luis Pass and only 1% through Rollover Pass (Pullen, et al., 1971). Tidal currents in Bolivar Roads reach 3.3 knots on flood and 4.3 knots on ebb. Faster ebb flow results from the hydrographic head developed when water is pushed into narrow bays and onto broad tidal flats (Fisher, et al., 1972).

(e) Winds. – The Galveston Bay estuary is subjected to moderate to strong winds that have an annual, average direction from the southeast (Brower, et al., 1972). Short lived but intense winds from the north are common in the winter, especially during December. Other winds add their impact during fall months but they are significantly less effective in generating waves, currents, and tides.

Bolivar Roads and San Luis Passes show alignment with the prevailing southeast winds. Such an occurrence suggests that the natural maintenance of these canals is in part the result of wind-tidal effect.

During the months of December through February, 15 to 20 northers, rapidly moving polar fronts, pass through the coastal area. Rain with winds up to 50 mph, accompany these sudden storms that have a duration of 24 to 36 hours. They not only affect the tides, but also tend to neutralize breakers and blow back-beach sand into the surf along the Gulf beaches.

(f) Currents. – The estuary's currents tend to be directly related not only to tides but also to winds. Current data relevant to these two forces have been included in those previous discussions.

(g) Storms. – Hurricanes are the principal mechanisms by which bays are flushed and these storms are reported to have raised the water level by as much as 14 feet (Lankford and Rogers, 1969). Their effect can be noted by inundation of large areas of the bay margin and by transport of shelf sand onto the shore-face of the beach. Carr (1967) shows that the Galveston Bay estuary has received some effect from 20-23 of these storms during the period of 1900-1956.

Tropical cyclones (winds $\geqslant$ 37 mph) occur on the average of 1 per 2.1 years in the Galveston-Freeport area whereas hurricanes (winds $\geqslant$ 72 mph) occur on the average of 1 per 3.2 years (Brower, et al., 1972). Snow has been recorded on only 4 occasions since 1895.

(2) Geology

Barrier Island Complex. – The seaward margin of the Galveston Bay complex is formed by Bolivar Peninsula and Galveston Island. This region is the eastern end of a nearly continuous chain of sand barriers that extends for almost 600 miles along the Mexican and Texas coast. Since their initial development as offshore sand bars, about 4000 years ago (Bernard and LeBlanc, 1965), Galveston and Bolivar barriers have broadened and lengthened by sand accretion. The Bolivar-Galveston barrier averages about 1-1/2 miles wide and is about 55 miles long. The Gulf shoreline of the barrier typically is straight or smoothly arcuate. The lagoonal shoreline is highly irregular and is formed by a series of washover deltas, old tidal inlets and distal ends of recurved spits.

The surface of the barrier is characterized by "ridge and swale" topography which parallels the Gulf shoreline (Lankford and Rogers, 1969). The swales have been interpreted as products of normal sand beach accretion and the ridges as storm berms created during beach erosion. The relief of the barrier ranges from sea level to a maximum of about 12 feet along the beach ridge crests. Shells and shell material are conspicuously present over the barrier.

Lagoon-Bay Complex. – The estuary bay is characterized by the mixing of both fluvial and marine environments and their resultant sediments. The degree of dominance of either environmental system is a function of river discharge, tidal interchange, water depth, and distance from river mouth or tidal inlet. It appears as if an environmental gradient exists along the axis of the estuary.

Since the Galveston Bay estuary is a site of active stream discharge and delta formation, fluvial-deltaic facies are obvious in the regions of the Trinity and San Jacinto Rivers (Lankford and Rogers, 1969). The fluvial subfacies consist of gravelly sand with silts and clays. The marsh subfacies are silt clays with plant material. Levee subfacies grade from muddy sand to silty clay.

The bay proper facies are typical of bay sediment distributaries with marsh deposits, sand, silt and clay, and shell materials (Rainwater and Zingula, 1962). Clams *(Rangia)* are abundant in the upper bay facies consisting of silty clays with traces of poorly sorted sand. The middle bay facies reveal silty and sandy clays with an abundance of shell material. The latter material is dominated by the oyster, *Crassostrea* and the mussel, *Brachidontes.* Poorly sorted lower bay facies range from sandy mud to silty clay. The inlet beach facies contains moderately sorted silty and clayey sands. This area reveals a diverse fauna that is a mixture of marine and lagoon forms.

(3) Chemistry

The highest concentration of total nitrogen and total phosphorus are found in the mouth of the Houston Ship Channel with decreasing concentrations toward the mouth of the bay (Copeland and Fruh, 1970). Dissolved oxygen shows a reversal with highest concentrations in the open water area and a minimum in the channel itself. The oxygen levels in the system varied from a minimum of 0.2 ml/l in East Bay to a maximum of 13.6 ml/l in Upper Galveston Bay over the period of 1963-1966. Oxygen values were maximum during the winter, decreasing through spring and reaching an annual low in the summer. It appears that this trend can be inversely correlated to temperature.

The table shown below was compiled from Fisher, et al. (1972), Copeland and Fruh (1970) and Pullen, et al. (1971). Total nitrogen represents the summation of ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and organic nitrogen. Total phosphorus reflects both dissolved and particulate forms of phosphorus compounds.

	Dissolved Oxygen (ml/l)	Total Phosphorus (mg/l)	Total Nitrogen (mg/l)	Average Salinity (°/oo)
Trinity Bay	5.5-6.1	0.5-0.8	0.8-1.2	10-16
Upper Galveston	4.9-7.0	0.5-2.0	1.0-4.0	18-20
Lower Galveston	4.9-6.2	0.2-0.5	0.6-1.0	18-26
East Bay	4.6-6.2	0.4	0.8-1.0	14-20
West Bay	No data	0.4-0.6	0.6	24-30

c. Resident and Transient Marine Biota

(1) Attached Vegetation

Submerged aquatic vegetation is practically non-existent in the turbid waters east of the Galveston Causeway. It does occur along the south shore of West Bay and in several of the secondary bays. Most of the emergent and associated marsh vegetation is located along the north shores of East and West Bays, the south shore of East Bay, and on the Trinity River delta. Phleger (1965) describes marsh development in the intertidal zone where the vegetation can colonize and trap

sediment during frequent flooding. They occur on the lagoon side of the sand barrier and fringe the landward side of the lagoon. Marshes are extensive on deltas which invade the lagoons and can occur as islands which develop as intra-lagoon bars.

Key Species. – The back side of the barrier islands supports salt marshes that display an orderly plant succession from the bay line to the higher parts of the barrier. The plant succession is (1) *Spartina alterniflora;* (2) *Batis, Salicornia,* and *Distichlis;* and (3) *Borrichia, Monanthocloe,* and *Suaeda* (Fisher et al., 1972).

In several areas the submerged bay margin is characterized by growth of marine grasses. The principal grassflats are along the back side of Galveston Island, off the mouth of Clear Creek, and along the western margin of the submerged part of the Trinity River delta. The Galveston Island grassflats consist chiefly of *Diplanthera* while those of the other two areas, generally areas of lower salinity, show *Ruppia* to be in dominance.

Species of the green algae *Caldophora* and *Enteromorpha* are abundant from late fall to early spring.

(2) Zoobenthos

Copeland and Fruh (1970) infer that, in general, the number of species of benthos and total number of benthic animals are very low in Galveston Bay. A seasonal effect was noted with benthos diversity being lower in July than during other seasons. It appears that a definite relationship exists between diversity indices and percent waste: i.e., as percent waste increases, the diversity index decreases.

A significant environment within the estuary is reefs built chiefly of the oyster *Crassostrea virginica.* These combine to form an area of 23 square miles of reefs ranging in size from small clumps to complexes up to 5 miles in diameter (Fisher, et al., 1972). The greatest concentration of reefs extends from Lower Galveston Bay into East Bay. Upper Galveston Bay is spotted with numerous small circular reefs. Larger reefs tend to elongate with the axis transverse to the dominant current direction. Such an occurrence indicates the oyster's dependency on circulating waters both for food and removing waste material. Favored bottoms for oyster-reef development are either fine, stable sands or stiff, compact muds. A large portion of the Galveston Bay estuary meets the previously mentioned requirements of oysters. In association with the reef environment are various mollusks, corals, and bryozoans.

Key Species. – *Crassostrea virginica* would have to be considered of major importance. The record harvest in 1965-66 yielded more than 4.3 million pounds of market oysters (Hofstetter, 1966). In the spring the southern oyster drill, *Thais haemastoma,* is common on the oyster reefs. Copeland and Fruh (1970) list the bivalves *Macoma mitchelli* and *Tellina alternata* as being dominant benthic organisms. Other common pelecypods in the bay include *Congeria leucophaeta, Mercenaria campechiensis, Mulinia lateralis, Ensis minor, Tagelus divisus, Cystopleura costata,* and *Brachidontes.*

Crustaceans of major importance include the blue crab *(Callinectes sapidus)*, the brown shrimp *(Penaeus aztecus)* and the white shrimp *(Penaeus setiferus)*. The post-larvae of the brown shrimp have been noted as appearing at nursery areas in three different groups, April, May, and September (Moffett, 1966). Galveston Bay fisheries normally produce 50% of the commercial blue crab catch (Moore, 1966). This catch accounted for 1,357,808 pounds of the total 2,758,548 pounds in 1966. By 1970 the Galveston Bay catch increased to 2,622,000 pounds of the Texas total of 6,285,500 pounds. The protected marshes serve as a nursery for juvenile crabs as well as a habitat for adults. The grass shrimp *(Palaemonetes pugio)*, an important forage species, shows up in extreme abundance in marshes and shallow *Spartina* beds. The mud crab *(Eurypanopeus depressus)* can be found with reefs in the low salinity areas while stone crabs *(Menippe mercenaria)* and *Petrolistes armatus* (porcellanid crab) are detected on higher salinity reefs.

(3) Pelagic Fauna

Zooplankton. – The copepod, *Acartia tonsa*, is by far the most dominant zooplankter over the entirety of Galveston Bay. During the months of April and July it constituted more than 90% of the catch (Copeland and Fruh, 1969). Crab zoea larvae and barnacle larvae are also found in abundance in the estuary. Other dominant zooplankton components (10% or more) found within the various bays include the pelagic tunicate, *Oikopleura*, and crustaceans, *Labidocera*, *Daphnia*, and ostracodes.

Ichthyofauna. – Fish habitat in the Galveston Bay estuary is of great importance. The finfish use the estuary as breeding, feeding, and nursery habitats.

The commercially and sports valuable species include trout *(Cynoscion nebulosus)*, redfish *(Sciaenops ocellata)*, black drum *(Pogonias cromis)*, flounder *(Paralichthys lethostigma)*, and sheepshead *(Archosargus probatocephalus)*. Breuer (1966) found these species represented by both juvenile and adult fish. According to Copeland and Fruh (1969), the Atlantic croaker *(Micropogon undulatus)*, the bay anchovy *(Anchoa mitchelli)*, and the sea catfish *(Galeichthys felis)* are also dominant members of the nekton. Large scale menhaden *(Brevoortia patronus)* and striped mullet *(Mugil cephalus)* populations are present throughout the estuary in all salinities. They are considered as important food items of sports and commercial fish.

(4) Bioproductivity

It is estimated that the Galveston Bay estuary produces about 1500 pounds of catchable-size fishes and crustaceans and harvestable-size oysters per acre annually. Texas Landings (1971) shows that Galveston and Trinity Bays produced 332,000 pounds of finfish valued at $44,019 and 12,101,300 pounds of shellfish with a value $3,919,976. It is worthy of note that Galveston Bay produced 82% of the state's oyster harvest and was also of major importance in the blue crab catch. Many more fishes and crustaceans produced in the estuary were taken in the Gulf of Mexico. It

is estimated that the estuary provides more than 70 million pounds of finfishes and shellfishes to the Texas Coast commercial fishery. (*National Estuary Study*, Vol. 5. Appendix G, pp. 32, 33)

(5) Marine Birds and Mammals

The Galveston Bay estuary is significantly important as a wintering habitat for some species of waterfowl, shore and wading birds, and other migratory birds. It is also a breeding area for some species of these birds. Principal species of waterfowl are mallard, pintail, baldpate, gadwall, greenwinged teal, shoveler, red-head, ring-necked duck, canvasback, lesser scaup, mottled duck, golden-eye, bufflehead, snow goose, white-fronted goose, Canada goose, merganser, and American coot. The principal shore and wading birds are ibises, egrets, herons, rails, snipes, gallinules, roseate spoonbills, plovers, gulls, terns, and pelicans. It is estimated that there are about 186 million waterfowl days annually expended in the estuary.

The estuary also provides habitat for squirrels, bobwhite, cottontails, swamp-rabbits, muskrats, nutrias, minks, otters, Texas red wolves, coyotes, raccoons, woodcock, armadillos, Attwater prairie chickens, eskimo curlews, and American alligators. The annual estimated fur harvest is 437,000 pelts, of which 90% are muskrats.

(6) Rare and Endangered Species

The roseate spoonbill is listed as a "peripheral species" by the Bureau of Sport Fisheries and Wildlife in its documentation of rare and endangered species of wildlife. The eskimo curlews, Attwater prairie chickens, Texas red wolves, and American alligators are endangered species.

6. Man's Activities in Zone II

a. Residential, Business, and Industrial Developments

Pertinent information on human developments within Zone II is condensed in Table A-6.

b. Fisheries

Table A-7 summarizes the commercial fishing activities for the principal bays in Zone II.

The Galveston Bay area leads all other bays in Zone II (and also all Texas bays) in the production of blue crabs, oysters and shrimp, but ranks third after Matagorda-Lavaca and Aransas-Copano for finfish catch in Zone II bays.

In regard to port landings, the ports of Zone II handle greater tonnage of shellfish than of finfish. The Galveston area led the state in shellfish landings in 1970. The Sabine area (Zone III) was second followed by Zone II ports of the Aransas area (third) and Matagorda area (fourth).

TABLE A-6

POPULATION AND BUSINESS DEVELOPMENTS IN ZONE II

	City or Town (listed from west to east)	Population	No. of Businesses*	Remarks (data from Texas Almanac, 1972; Texas Highway Dept., 1970; AAA, 1971)
Corpus Christi Bay	Corpus Christi	284,382	3,318	Major deepwater port, industrial & agricultural center, and one of Texas' most popular seacoast recreational centers. Fine residential areas south of city along Corpus Christi Bay. University of Corpus Christi, Del Mar College, U.S. Naval Air Station (SE of city). Prominent industries: American Smelting & Refining Co., Suntide Refining Co., Pittsburgh Plate Glass Co., Corn Products Refining Co., Halliburton-Portland Cement Co., & Celanese Corp.
Corpus Christi Bay	Ingleside	3,763	35	On the north shore of Corpus Christi Bay (across the bay from Corpus Christi). A residential area and center for boating activities with two large marinas for pleasure craft. Reynolds Aluminum plant.
Aransas Bay	Aransas Pass	5,831	162	Gateway to the offshore islands of St. Joseph and Mustang, Aransas Pass is an area which attracts tourists, hunters, fishermen, naturalists, & artists. Key industrial activity is shrimp fishery & fleet of shrimp boats.

TABLE 6 (Continued)

	City or Town	Population	No. of Businesses*	Remarks
Aransas Bay	Port Aransas	1,218	42	Located on Mustang Island across Aransas Bay from Aransas Pass. A resort village, which attracts tourists for fishing and beach activities. Motels & seafood restaurants attract tourists. University of Texas' Institute of Marine Science, located on the jetty, an important research and educational center for marine biology and oceanography.
Aransas Bay	Rockport	3,879	146	Located on Aransas Bay. Fishing, boating, and beach activities are tourist attractions here. Motels & hotels, many fishing piers. Texas Parks & Wildlife Marine Laboratory, on the bay front, for fisheries research and displays of marine life.
Aransas Bay	Fulton	1,101	24	2 fishery processing plants here.
San Antonio Bay	Austwell	284	5	2 fishery processing plants here.
San Antonio Bay	Long Mott	76	4	Union Carbide plant here and port facility.
San Antonio Bay	Seadrift	1,092	15	3 fishery processing plants here.

TABLE 6 (Continued)

	City or Town	Population	No. of Businesses*	Remarks
Matagorda-Lavaca Bay	Port Lavaca	10,491	237	Located on Lavaca Bay (upper Matagorda Bay). Commercial fishing center with a large shrimp fleet. Manufacture of aluminum & chemicals are important industries. Surrounding area winter feeding ground for water-fowl and attracts many hunters.
	Port O'Connor	350	12	Located at mouth of Matagorda Bay at Cavallo Pass. Matagorda Island, across the Bay, is privately owned and not open to the public Ferry service to island operated by U.S. Air Force, which maintains a bombing range at north end of island. Entry prohibited by unauthorized persons. Remainder of island is a privately owned ranch, which grazes 3,000 head of cattle (Andrews, 1971).
	Palacios	3,642	65	Located on upper Matagorda Bay. Fishing & shrimping are the primary industries, but there is also hunting, tourism, boat and brick plants, and shell production.
	Matagorda	605	10	Located between Matagorda Bay and East Matagorda Bay on the Colorado River at its junction with the Intracoastal Waterway. Matagorda Peninsula, undeveloped area with sand dunes, grasslands, trees, and good beaches, but no good access roads. Presently used for cattle grazing.

TABLE 6 (Continued)

Region	City or Town	Population	No. of Businesses*	Remarks
	Freeport	11,997	258	Located at the mouth of the Brazos River in Brazoria County. Large installations of chemical manufacturing plants (Dow, Stauffer, Shell Oil Hydrocarbon Plant). Also saline conversion plant and shrimp processing plants.
Galveston Bay	Galveston	61,809	596	Located at the eastern end of Galveston Island. Connected to mainland, 2 miles away, by causeway. Tourism & recreation, seaport facilities (revenue of \$61 million annually) and the University of Texas Medical Center (\$25 million annually) provide the primary economic base. Texas A&M University's Moody College of Marine Sciences and Maritime Resources, including the Texas Maritime Academy, located on Pelican Island in lower Galveston Bay just north of Galveston (marine research, teaching, and maritime training on 80-acre facility, also docks for research & training vessels). Port of Galveston has berthing space for 40 ocean-going steamers and is the nation's greatest cotton port & one of the outstanding sulphur ports. Main exports: grain, flour dried beans, & scrap metal. Leading imports: raw sugar, bananas, burlap, asbestos fibers, tea, woodpulp, & ore concentrates.

TABLE 6 (Continued)

	City or Town	Population	No. of Businesses*	Remarks
Galveston Bay	Texas City	38,908	328	Located on lower Galveston Bay (across bay from Galveston). Heavy industrial center, primarily oil refining. Galveston-Texas City metropolitan area has a total population of 169,812.
	Baytown	43,980	414	Located on upper Galveston Bay. Heavy industrial center, primarily oil refining.
	Houston	1,985,031	16,992	Largest city in Texas and in the South. 13th largest *in United States. Located 50 miles northwest (in-land)* from Galveston. Leading center for manufacturing, especially petrochemicals, oil production & distribution, medical & other research, home & regional offices of leading firms. Payrolls exceeding $2 billion. Ranks third nationally in seaport tonnage (via Houston Ship Channel).
	Anahuac	1,881	50	Located on upper Trinity Bay near the mouth of the Trinity River.
	Port Bolivar	3,400	15	5 fishery processing plants here.
	Gilchrist	750	10	1 fishery processing plant here.
	High Island	500	15	

* *Number of rated business establishments that are given a rating by* Dun & Bradstreet.

TABLE A–7

1970 FINFISH AND SHELLFISH CATCH IN TEXAS WATERS

	Corpus Christi & Nueces Bays		Aransas & Copano Bays		San Antonio Bay System		Matagorda & Lavaca Bays		Galveston & Trinity Bays	
	Pounds (in thousands)	Value (in thousands)	Pounds (in thousands)	Value (in thousands)	Pounds (in thousands)	Value (in thousands)	Pounds (in thousands)	Value (in thousands)	Pounds (in thousands)	Value (in thousands)
Finfish	113.2	$ 23.0	430.3	$ 78.1	213.2	$ 41.5	456.9	$ 79.7	332.0	$ 44.0
Blue Crabs	—	—	878.1	$ 79.1	531.7	$ 48.3	782.0	$ 70.7	2,622.0	$ 244.8
Oyster Meats	—	—	120.2	$ 54.3	221.8	$100.7	479.5	$ 183.3	3,850.2	$1,700.5
Shrimp	345.7	$ 91.9	1,327.0	$432.9	1,306.8	$405.9	1,997.5	$ 740.8	5,125.5	$1,974.4
Total	458.9	$114.9	2,755.6	$681.0	2,273.5	$596.4	3,715.9	$1,074.5	12,429.7	$3,963.7

(after Texas Landings, 1971).

In finfish landings, the ports of the Zone II areas rank third (Aransas), fourth (Galveston) and fifth (Matagorda) after first and second Sabine (Zone III) and Laguna Madre ports (Zone I).

Of the 163 fishery processing plants of the Texas coastal region in 1968 listed by Miloy and Copp (1970), 108 are located in Zone II. Freeport, with 13, and Galveston with 12 head the list, followed by Aransas Pass with 9, Houston with 8, and Port Lavaca with 8. Palacios and Seabrook each had 6, and Matagorda and Port Bolivar each had 5 fishery processing plants in 1968.

Freeport ranks second after Brownsville (Zone I) in number of wholesale dealers in fishery products.

In addition to the commercial fishery activities of Zone II, Corpus Christi, Rockport, Aransas Pass, and Galveston are popular sport fishery areas. It is estimated that about 500,000 man-days of sport fishing occur annually in the Aransas estuary (U.S. Department of Interior, 1970, vol. 3), and 2.6 million man-days annually occur in Galveston Bay.

c. Recreation and Leisure

(1) General Tourist Areas

(a) Corpus Christi. Tourism in Corpus Christi generates over $135 million annually (Miloy and Copp, 1970). Fishing from numerous municipal piers, jetties, and miles of beach and seawall. Yacht basin and marina for boating interests. Hotels, motels, beaches (Texas Highway Dept., 1970).

(b) Port Aransas. Motels, seafood restaurants, parks, and beach camping areas are tourist attractions. Two rock jetties extend a mile into the Gulf, and are used for fishing. An 18-mile stretch of sandy beach extends southwestward from Port Aransas on the Gulf side of Mustang Island.

(c) Rockport. Fishing and beach activities are the main recreational pursuits at Rockport. Excellent beaches, water skiing basin, fishing from old causeways crossing Copano Bay, boat ramps, and party boat fishing facilities available at the Rockport Yacht Basin are tourist attractions as well as the numerous public fishing areas and piers. Also hotel-motel fishing piers for guests (Texas Highway Dept., 1970). The City of Rockport and Aransas County have park and beach facilities on a fill peninsula adjacent to Little Bay (U.S. Dept. of Interior, 1970, vol. 30). Aransas National Wildlife Refuge and several state recreational areas are located just north of Rockport.

(d) Galveston. Galveston ranks sixth in the state of Texas as a convention center. During 1970, over 2 million tourists visited Galveston, 98,000 of which were convention delegates. Some of the main tourist attractions are marinas, fishing facilities, historical attractions, and beach sport facilities (Boykin, 1971). Fishing is a

favorite activity here, with five free fishing piers extending into the Gulf and up to 50 varieties of salt-water fish in the adjacent waters. Along the 32 miles of beachfront are located numerous bathhouses, beach apartments and cottages, large hotels, and amusement centers.

(2) National Wildlife Refuges and Preserves (Figure A-10)

(a) Aransas National Wildlife Refuge. Located 10-15 miles north of Rockport on Blackjack Peninsula between San Antonio Bay on the northeast, Aransas Bay on the south, and St. Charles Bay on the west. Occupying 54,829 acres, this area is the wintering ground for waterfowl, shore, wading, and other migratory birds. It is also a breeding area for some species of these birds. Over 80,000 people visited the refuge in 1971 for sightseeing, nature observation, hiking, and photography. Principal species of waterfowl are mallard, pintail, baldpate, gadwall, green-winged teal, blue-winged teal, shoveler, redhead, canvasback, lesser scaup, ringnecked duck, goldeneye, bufflehead, mottled duck, Canada goose, snow goose, blue goose, red-breasted merganser, and American coot. The principal shore, wading, and water birds are ibis, cranes, egrets, herons, rails, gallinules, spoonbills, snipes, plovers, gulls, terns, and pelicans (U.S. Dept. of Interior, 1970, vol. 3). The rare whooping crane, which numbered only 48 individuals in 1967, winters here (Reed and Reid, 1969). About one-third of all winter habitat for the whooping cranes is located in the Aransas Estuary area. The rare roseate spoonbill also breeds at the refuge and on several islands in the Aransas estuary (U.S. Dept. of Interior, 1970, vol. 3). Other wildlife at the refuge includes peregrine falcons, wild turkeys, caracaras, white-tailed hawks, deer, bobcat, Texas red wolves, coyote, javelina, raccoon, opossum, striped skunk, cottontail rabbit, blacktailed jack rabbit, nutria, and alligator (U.S. Fish & Wildlife, 1972).

(b) San Bernard National Wildlife Refuge. Located approximately 15 miles southwest of Freeport on 14,915 acres in Brazoria and Matagorda counties. Primary species of wildlife include geese, ducks, wading birds, shore birds, and Texas red wolves. The waterfowl population averages about 3000 Canadian geese, 74,000 blue and snow geese, and less than 20,000 ducks. There were 508 visitors in 1971 (U.S. Fish & Wildlife Service, 1971 and 1972).

(c) Brazoria National Wildlife Refuge. Located some 25 miles northeast of Freeport on Galveston West Bay and occupying 9530 acres. Primary species of wildlife includes geese, ducks, alligators, nutria, raccoons, armadillo, muskrat, eastern cottontail, opossum, striped skunk, swamp rabbit, red wolf, river otter, beaver, and black-tailed jack rabbit. There were 797 visitors in 1971 (U.S. Fish & Wildlife Service, 1972).

(d) North Deer Island (100 acres), *Vingt-et-un Island* (40 acres), and *West Bay Bird Island.* These three islands, located in the Galveston Bay area, are controlled by the National Audubon Society as sanctuaries for shore and wading birds (U.S. Dept. of Interior, 1970, vol. 5).

(e) Anahuac National Wildlife Refuge. A 9940-acre preserve located 18 miles southeast of the city of Anahuac (population 1881) on upper Trinity Bay (upper Galveston Bay system) in Chambers County, it provides sightseeing, nature observation, and photography. Visitor facilities limited to primitive roads (Reed and Reid, 1969). 18,552 visitors in 1971. Primary bird species include lesser Canada, snow and blue geese; mottled ducks; masked ducks; canvasbacks; yellow rails; bald eagles; and peregrine falcons. Other wildlife includes alligators, nutria, muskrat, swamp rabbit, opossum, raccoon, armadillo, river otter, mink, red wolf, bobcat, and spotted skunk.

(3) State and County Parks and Recreation Areas

(a) Port Aransas Park, County Camping Area, on Mustang Island near Port Aransas, provides camping facilities; bathhouses; lifeguards; fishing from beach, breakwater, and off the 900-foot pier.

(b) Connie Hagar State Wildlife Sanctuary occupies water areas in Little Bay and Aransas Bay in the Rockport-Ninemile Point-Fulton area. The sanctuary is used by many species of waterfowl and shore and wading birds (U.S. Dept. of Interior, 1970, vol. 3). Exact acreage and other detailed information about the sanctuary are not readily available.

(c) Goose Island State Park has facilities comprising 307 acres located in Aransas Bay near the Aransas National Wildlife Refuge north of Rockport, with boat launching, fishing, picnicking, swimming and camping. There were 320,000 visitors in 1968 (U.S. Dept. of Interior, 1970, vol. 3).

(d) Copano Causeway State Park. Traversing the entrance to Copano Bay, the old Copano Causeway, taken over by the state, has been breached and converted to a fishing pier for the public. Facilities also include a boat ramp and restrooms. Occupies an area of 6 acres. About 72,000 people used the facility in 1968 (Texas Almanac, 1972 and U.S. Dept. of Interior, 1970, vol. 3).

(e) Port Lavaca Causeway State Recreation Area. Boat ramp and fishing area on a 3200-foot fishing pier made from old causeway which crosses Lavaca Bay. Area occupies 2 acres (Texas Almanac, 1972).

(f) Indianola State Historical Area is located southeast of Port Lavaca near Port O'Connor.

(g) Velasco State Recreation Area. Beach recreation area and scenic park on Gulf Coast near Freeport. The park is defined as that area between low tide and high tide on the Brazoria County portion of the Texas coastline (Texas Almanac, 1972).

(h) Galveston Island State Park. 1922 acres located 8 miles southwest of Galveston. It is an undeveloped area with sand dunes and grasslands. Area closed pending development plans (Texas Almanac, 1972).

F. ZONE III – THE SABINE-NECHES ESTUARY

1. Summary

Zone III of Texas, which includes the Sabine-Neches Estuary, was set apart from the bays of Zone II because (1) it has the lowest average salinity of the Texas bays, (2) it has the highest average annual rainfall, (3) it receives the largest river of Texas, (4) it is located wholly in the humid climatic zone, and (5) it is the only major embayment of Texas that does not have a characteristic barrier island-lagoon development. These factors have distinctive effects on the biology of the estuary that are detailed in the appropriate section.

The Sabine Lake complex is situated in the extreme southeastern corner of Texas and in the southwestern corner of Louisiana. It includes the tidal parts of the Sabine River, the largest of Texas in terms of annual discharge volume, and the Neches River, Sabine Lake, the Sabine-Neches and Port Arthur Canals and Sabine Pass to the Gulf of Mexico (Figure A-17).

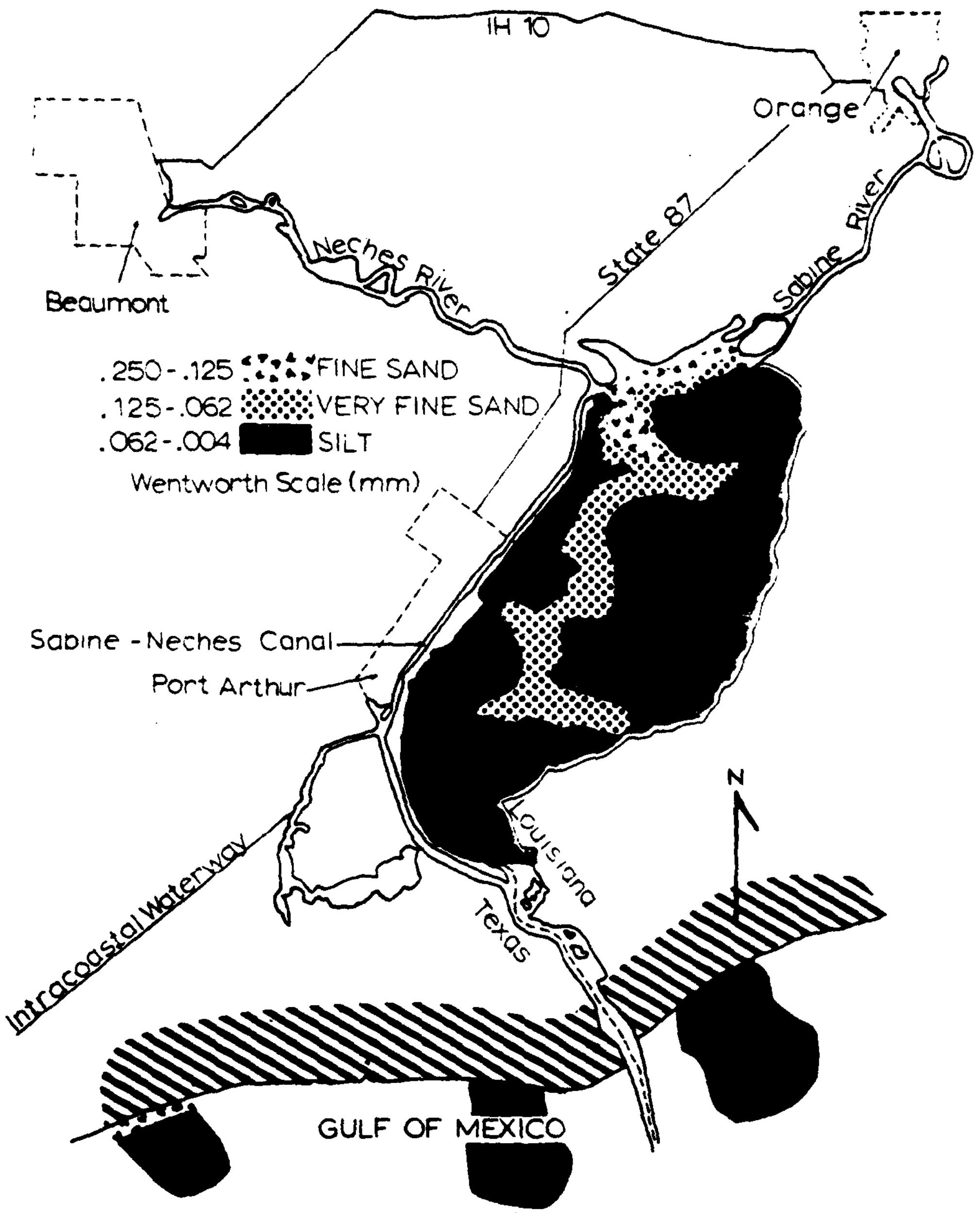
Located in the humid climatic zone (Thornthwaite, 1948) where annual rainfall exceeds annual evaporation by 12 inches or more this brackish estuarine system represents the low-salinity end of the gradient that extends from Laguna Madre. Rainfall is distributed throughout the year, but thunderstorms and occasional tropical cyclones place the period of maximum rainfall in summer. Annual rainfall around the Lake approaches 53 inches.

The Sabine region has two major ports, Port Arthur and Beaumont and is the second largest oil refinery center in the Texas coastal area. It is germane to point out that the port cities of the Texas portion of Zone III handle the greatest percentages of liquid cargoes of any other port cities of Texas except for Texas City in Zone II, which handles 98% liquid cargo. Sabine Pass handles 94% liquid cargo, Beaumont and Port Arthur each handle 91% liquid cargo (Figure A-9a) (Miloy and Copp, 1970).

2. Physical Characteristics

a. Hydrology

(1) Physiographic. – Along its northern boundary Sabine Lake receives both the Neches and Sabine rivers; its southern extension is connected with the Gulf of Mexico via Sabine Pass, a narrow inlet some seven miles long. This complex, which is called the Sabine-Neches Estuary in this report, covers an area of about 100 square miles. Overall it includes both natural and man-made features of no small import. Thus the complex is constituted of the tidal parts of both rivers, as well as the Lake, the Sabine-Neches and Port Arthur canals, the adjacent Intracoastal Waterway, and Sabine Pass (Hahl and Ratzlaff, 1970). The boundary between Texas and Louisiana at this point runs down the center of the Pass, Lake, and Sabine River (Figure A-17).



(after Hahl and Ratzlaff, 1970, and Kane, 1967)

FIGURE A–17 SABINE-NECHES ESTUARY, SEDIMENTS OF SABINE LAKE, AND ADJACENT GULF SHORE

Water depths in Sabine Lake range from 2 to 10 feet below mean low water, but most of the lake has depths around 5 to 8 feet. Through dredging, water depths at mean low water have been increased to 40 or more feet in the rivers, canals, and pass, and to about 15 feet in the Intracoastal Waterway. Sabine Lake proper has a surface area of about 70 square miles.

(2) Salinity. – The salinity values of this estuarine complex are controlled largely by the interplay between river inflow and saline intrusions from the Gulf of Mexico via Sabine Pass. The low salinities throughout most of the complex indicate that river influences predominate in this regard. Thus surface salinities in Sabine Lake proper range from 0.0 to 18.7°/oo with an overall average of about 6.8°/oo. In Sabine Pass salinities range from 0.0 to 29.4°/oo with an overall average of 15.1°/oo, whereas in the Gulf adjacent to the Pass the corresponding figures are 8.8 to 30.0°/oo with an average of 24.8°/oo. As suggested above these large salinity ranges are primarily attributable to the large but fluctuating discharge rates of the Neches and Sabine Rivers into the Lake.

Hahl and Ratzlaff (1970) estimate that in 1968 the combined flow of these two rivers amounted to about 9690 cubic feet per second or about 7 million acre-feet per year. The larger part of this flow is contributed by the Sabine, which is the largest river of Texas at the present. Stevens (1961) reveals that the peaks of river discharge ordinarily occur in the period from January to July. For instance, in January 1959, the two rivers discharged a total of 1.3 million acre-feet into Sabine Lake, whereas in September of the same year the total was about 0.25 million acre-feet. These substantial changes in runoff bring in the early part of the year virtually fresh water as far as Sabine Pass, whereas later in the same year very saline waters may penetrate to the river deltas.

The other important factors controlling salinity changes in the complex are wind and tide. Kane (1967) shows that incoming tides and strong southerly winds cause saline water from the Gulf to surge into the Pass and Lake. Conversely, winds from the north impede the entrance of water from the Gulf with consequent lowering of salinity.

Kane (1967) states that bottom-water salinities in the Lake are generally 0.6 to 1.3°/oo higher than those of the surface. Important exceptions to this situation occur when at time of maximum river flow the entire water column is fresh down to the Pass, and when some wind and tide conditions cause sufficient turbulence to extend the mixed layer to the bottom. Both of these phenomena, when coupled with the fact that substantial volumes of Gulf water are pushed into the Lake and tributaries by strong winds, suggest that offshore oil spills could well spread far and wide into the Sabine-Neches Estuary, especially if oil appeared at the Pass entrance during the latter part of the year.

(3) Temperature. – Ranges of temperature, as well as averages will be given for surface waters at three locations in the estuarine complex.

Sabine Lake:	10.8°C (Jan.) to 31.7°C (July) 21.4°C overall average
Sabine Pass:	10.3° to 29.4°C 20.8°C overall average
Gulf of Mexico near Pass:	11.1°C to 29.4°C 22.4°C overall average (Kane, 1967)

Bottom water temperatures in the Lake are lower than those of surface waters by about 1.3°C in summer and 0.5°C in winter. The overall averages of atmosphere and surface water temperatures differ by less than a degree centigrade.

(4) Tides. – Most of Sabine Lake is affected by astronomic tides but the range averages about one foot. Prolonged and strong southerly winds raise the water surface at the Lake's north end by several feet. Tropical storms in the summer and fall have caused tides of 14 feet above mean low water at Sabine Pass and, according to Kane (1967), 7 feet above mlw at Port Arthur in Sabine Lake. Floods in the Neches and Sabine Rivers cause water-level rises that are of short duration. Even so they can range up to 13.6 feet above mlw at Beaumont and to 7.6 feet at Orange. Strong north winds of winter and early spring reduce water level markedly forcing substantial quantities of low-salinity water into the Gulf.

(5) Winds. – The prevailing winds in this region have strong southerly and easterly components except in January when the northerly component predominates. The greatest persistence in these southerly to easterly winds occurs from March to September, when the Bermuda High has intensified in strength (Brower et al., 1972). During the cooler months, as the Bermuda High decreases in strength, the extratropical cyclones and their associated cold high pressure systems intensify over the adjacent continent. These continental highs begin to dominate in January giving rise to prevailing winds from the north. The "northers" are often strong and gusty, but the highest winds are likely to be observed during tropical cyclones from June through October.

(6) Storms. – Brower et al. (1972) report that 32 tropical cyclones have been reported in the Sabine region through 1971 and that all of these carried winds of 34 knots or over and 15 of them had winds of over 64 knots. It is expected that winds with speeds of 100 knots will occur in the Sabine Region once every 25 years.

b. *Geology*

The Sabine and Neches Rivers deliver about 7 million tons of silt to Sabine Lake each year. No data were available on the turbidity of the lake proper, but it is judged to be high in view of the fact that Secchi disc measurements in the feeder rivers are regularly less than one meter. According to Kane (1967) the sediments composing the bottoms of Sabine Lake and adjacent water bodies are, in the wet

state, grayish and blackish, very fine sandy and silty mud or silty and clayey mud. Some very fine sand and fine sand are present in the northern part of Sabine Lake; very fine sand also is present along the western part of the Gulf of Mexico shoreline. The sediments are generally soft, have a high water content, and contain variable amounts of shell and plant materials. Mechanical analyses of the bottom sediments of the lake performed by Kane (1967) show that the dominant sedimentary type, based on mean grain size, is silt and that very fine sand and fine sand are present in smaller amounts.

c. Chemistry

The data on nutrient levels in Sabine Lake are not sufficiently inclusive as to permit more than listing ranges of values for the following parameters (unless otherwise stated values are in mg/liter):

pH	5.8- 9.5	overall average of 7.6
Dissolved O_2	1.6-12.9	
BOD	0.8- 2.9	
Silica	3.8- 9.8	
NO_3	1.0- 3.3	
NO_2	0.04-0.23	
NH_4	0.12-0.99	
PO_4		
ortho	0.09-0.21	
Total	0.16-0.23	

The above values were taken from Hahl and Ratzlaff (1970).

3. Resident and Transient Marine Biota

a. Invertebrates. – Only 10 species of invertebrate animals were collected by Stevens (1961) in the year 1959-1960. The most important of these were the commercial oyster [*Crassostrea virginica* (Gmelin)], the brown shrimp (*Penaeus aztecus* Ives), and the white shrimp [*Penaeus setiferus* (Linnaeus)]. Less important species taken by Stevens were the clam (*Rangia cuneata*), which is present throughout the lake but reaches highest population densities in the northern (lower-salinity) part; the fresh water shrimp *Macrobrachuim ohione* which also prefers low salinities (less than 7°/oo) and thus thrives during high river inflow; the blue crab, *Callinectes sapidus*, which supports a small commercial crab fishery in the southern part; and the squid *Lolliguncula brevis*, which also lives in the southern higher salinity part of the lake.

b. Fishes. – Stevens (1961) provides a check-list of fishes captured by the Texas Game and Fish Commission vessel using a 10-foot otter trawl at monthly intervals from February 1, 1959 to January 31, 1960. The list contains 63 species of fishes ranging from those frequently associated with fresh water to those thought of as typical marine species. The menhaden fishery continues to be a substantial one in

this area, but commercial quantities are taken only from the adjacent Gulf of Mexico, not from the Sabine Lake.

4. Man's Activities

a. Residential, Business, and Industrial

Pertinent information on human developments within Zone III is condensed in Table A-8.

b. Fisheries

In 1970 the Sabine Lake area produced the lowest dollar value ($100) and poundage (500 lb) for finfish production of any bay in Texas. It showed the second lowest dollar value ($73,000) and poundage (710,000 lb) for shellfish production, after Laguna Madre-Baffin Bay (Zone I). Blue crabs account for the greatest portion of the shellfish poundage (685,000 lb) and dollar value ($64,000) in Sabine Lake, but this is nowhere near the amount of blue crabs produced in Galveston Bay in Zone II (2.6 million pounds and $245,000).

In fish landings, however, which included Gulf of Mexico catches outside of Sabine Lake proper, the Sabine ports lead all other Texas port areas with over 57 million pounds of fish landed per year in 1971-72 (Texas Landings, April, 1971–March, 1972). The bulk of the poundage is landed in the May–September period and is accounted for by menhaden and other unclassified fish used for bait, reduction, and animal food. During the remainder of the year red snapper accounts for the greatest monthly finfish poundage.

Of the 163 fishery processing plants listed in the Texas coastal area in 1968 by Miloy and Copp (1970), the Texas portion of Zone III contains nine (four at Port Arthur, four at Sabine Pass, and one at Beaumont).

c. Recreation and Leisure

(1) General Tourist Areas. – This area is not so noted as a tourist area compared to the other beach and bay areas of Texas.

(2) National Wildlife Refuges and Preserves

Sabine National Wildlife Preserve. 142,845 acres on the east shore of Sabine Lake in the state of Louisiana. Nature study, photography, hiking, etc. Primary species include blue geese, snow geese, mottled ducks, roseate spoonbills, glossy ibises, and alligators (U.S. Fish & Wildlife, 1972).

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TABLE A–8

POPULATION AND BUSINESS DEVELOPMENTS IN ZONE III

City or Town	Population	No. of Businesses*	Remarks
Sabine Sabine Pass	75 850	1 10	Located near the mouth of Sabine Lake 8-10 miles from the city of Port Arthur. Four fishery processing plants are at Sabine Pass.
Port Arthur	57,371	546	Located on NW shore of Sabine Lake, 11 mi. from the Gulf of Mexico and connected to the Gulf by a ship channel 36 feet deep and 400 feet wide at the bottom. Main industries are oil refining and petrochemical products. Major plants in the city include Gulf Oil Corp., Texas Co., Atlantic Refining Co., and Koppers Co., Inc. Four fishery processing plants are here.
Beaumont	115,919	1,665	Located about 20 miles inland from Port Arthur and Sabine Lake. Major ship and barge-building site and a leading inland port (via deepwater channel). One of largest concentrations of petroleum refineries in nation at Beaumont and surrounding area. Chemical, synthetic rubber and sulphur industries. Manufacture of deep-sea and dry-land oil drilling apparatus and oil processing equipment. Lamar State College of Technology is here.
Orange	24,457	368	Located on the Intracoastal Waterway and the Sabine River at the boundary of Texas and Louisiana. Industries include steel fabricating, paper manufacturing, rice milling, woodworking, expanding chemical industry, lumber.

*Number of rated business establishments that are given a rating by Dun and Bradstreet.

(data from Texas Almanac, 1972; Texas Highway Dept., 1970; AAA, 1972)

II. THE CONTINENTAL SHELF (ZONES IX, X, XI (part); XX, XXI; and XXII)

A. INTRODUCTION

Constituting less than one percent of the surface area of the oceans, the Gulf of Mexico may be considered small in a physiographic sense; indeed, it is in some ways little more than a large estuary, particularly its western half. The Gulf is even smaller in a functional sense. If we take the outer edge of the continental shelf to lie at a depth approaching 100 fathoms (Figure A-18), then nearly 35 percent of the Gulf's surface lies over this shelf. Still, it is estimated that only 1.3 percent of the Gulf's total volume of water lies over this continental shelf that has an average depth of only 27 fathoms (Pequegnat, 1970). One must be impressed by the fact that about one-third of the Gulf is covered by little more than a hundredth of its waters, a part of which is fresh runoff. Indeed, the annual runoff from the Mississippi-Atchafalaya complex, much of which courses westward, does comprise 10 percent of the volume of water on the continental shelf in the western Gulf of Mexico (Moody, 1967). Perhaps the above considerations are sufficient to demonstrate how vulnerable to change this film of shelf water really is. Even so, these waters of Texas and Louisiana include the most productive shrimp grounds in the United States (Figure A-19). And, as we shall see in this section, these animals – and many others, including some finfishes – belong neither to lagoon nor to shelf alone, but to both.

B. PHYSICAL CHARACTERISTICS

1. Hydrology

a. Physiographic. – Much of the shelf region shares weather and general climatic factors with the embayment regions of the coastal zone. Since these parameters were discussed quite thoroughly in earlier sections, they will be omitted here.

It is appropriate to emphasize here, however, that as we move from bay to shelf the waters change rather gradually from estuarine along the shore to oceanic over the outer edge of the continental shelf (Figure A-20).

b. Salinity. – Average salinity conditions and trends of surface waters in the northwestern Gulf are shown in Figure A-21. If we project a line from the nearshore zone off Sabine Pass to the outer shelf (across Zones XI, XXI, and XXII), salinities increase markedly from 29°/oo to 36°/oo. Nearly the same change (29 to 35°/oo) occurs along a line from Sabine Pass to off Port Isabel in the southwest (Figure A-21). In some years both of these gradients may be much steeper as a result of fresh water runoff which increases from Port Isabel to Sabine. Thus, in April 1963 (rain is generally heaviest here from March to May) the salinity off Sabine Pass reached 22°/oo at a time that it was 36.5°/oo on the outer shelf and in excess of 30°/oo off Port Isabel (Figure A-22).

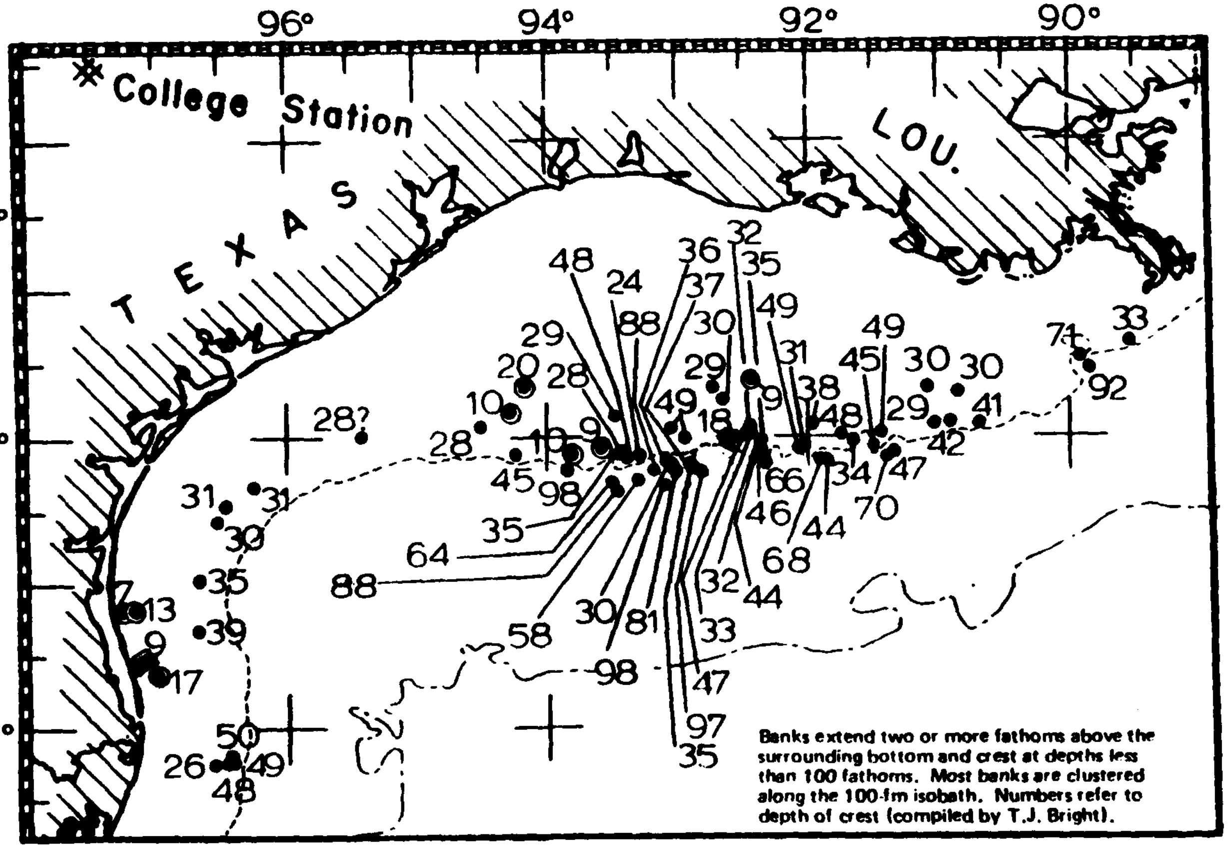


FIGURE A-18 DISTRIBUTION OF SUBMARINE BANKS IN THE NW GULF

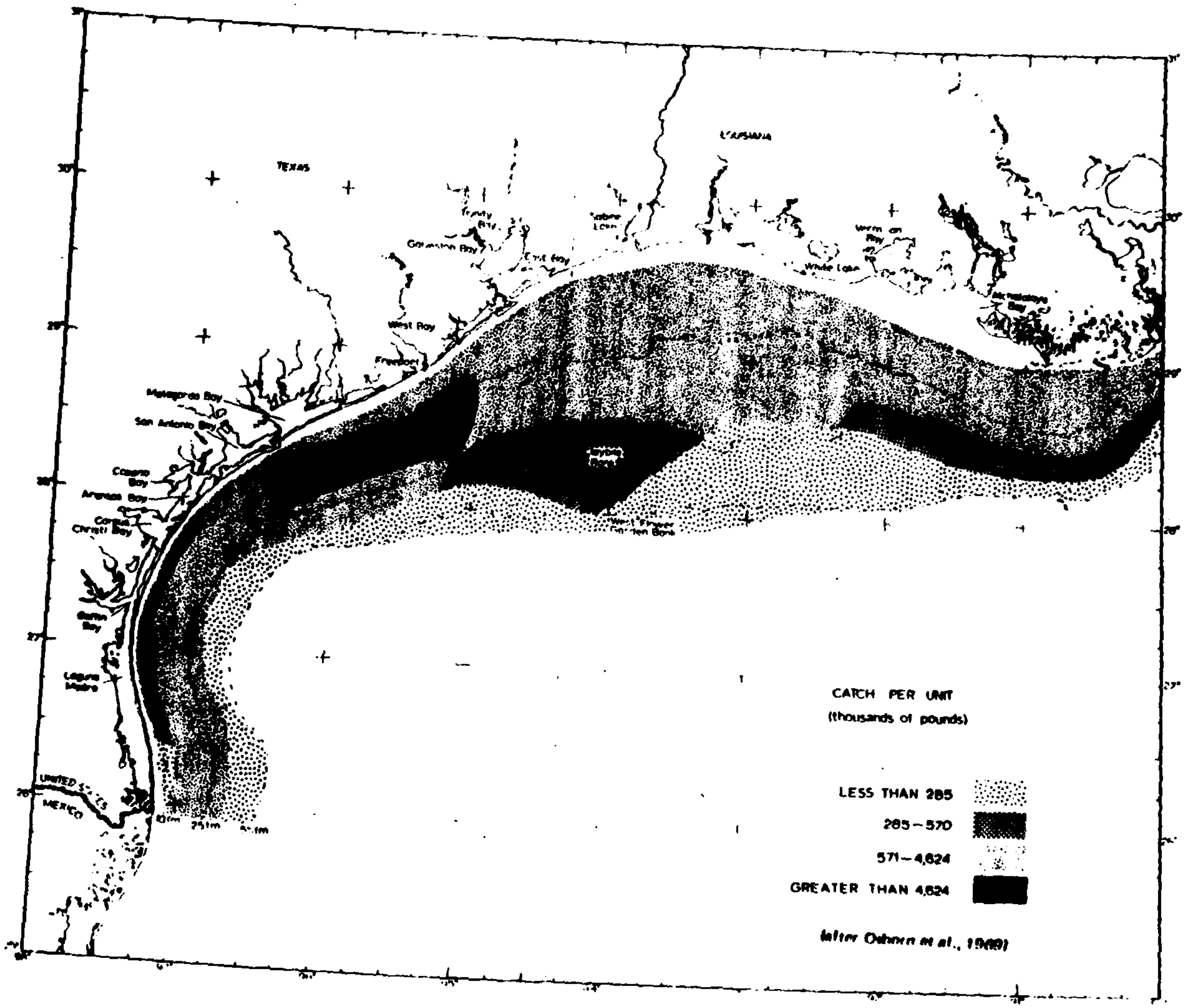


FIGURE A–19 TOTAL OPEN GULF SHRIMP LANDINGS, 1969

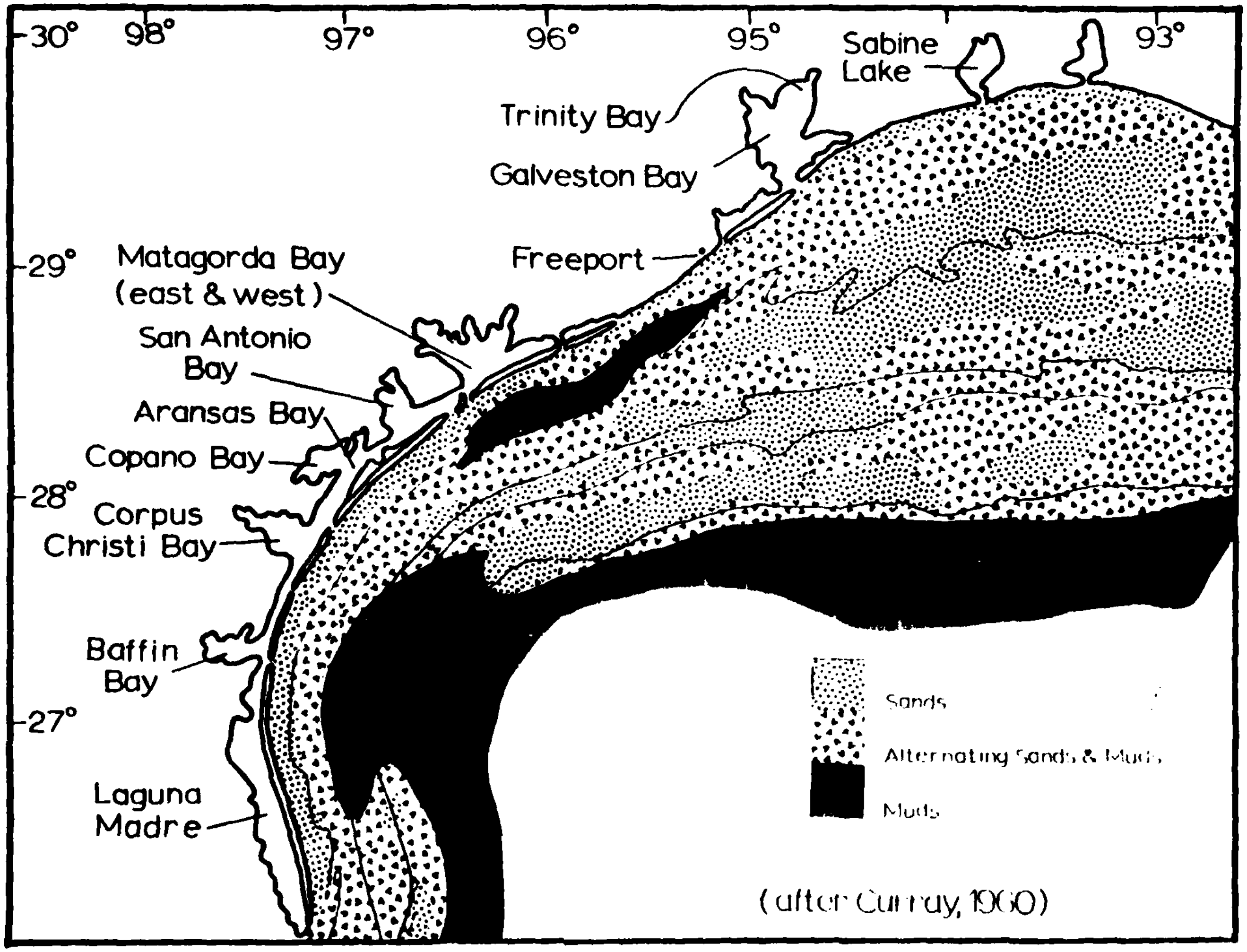
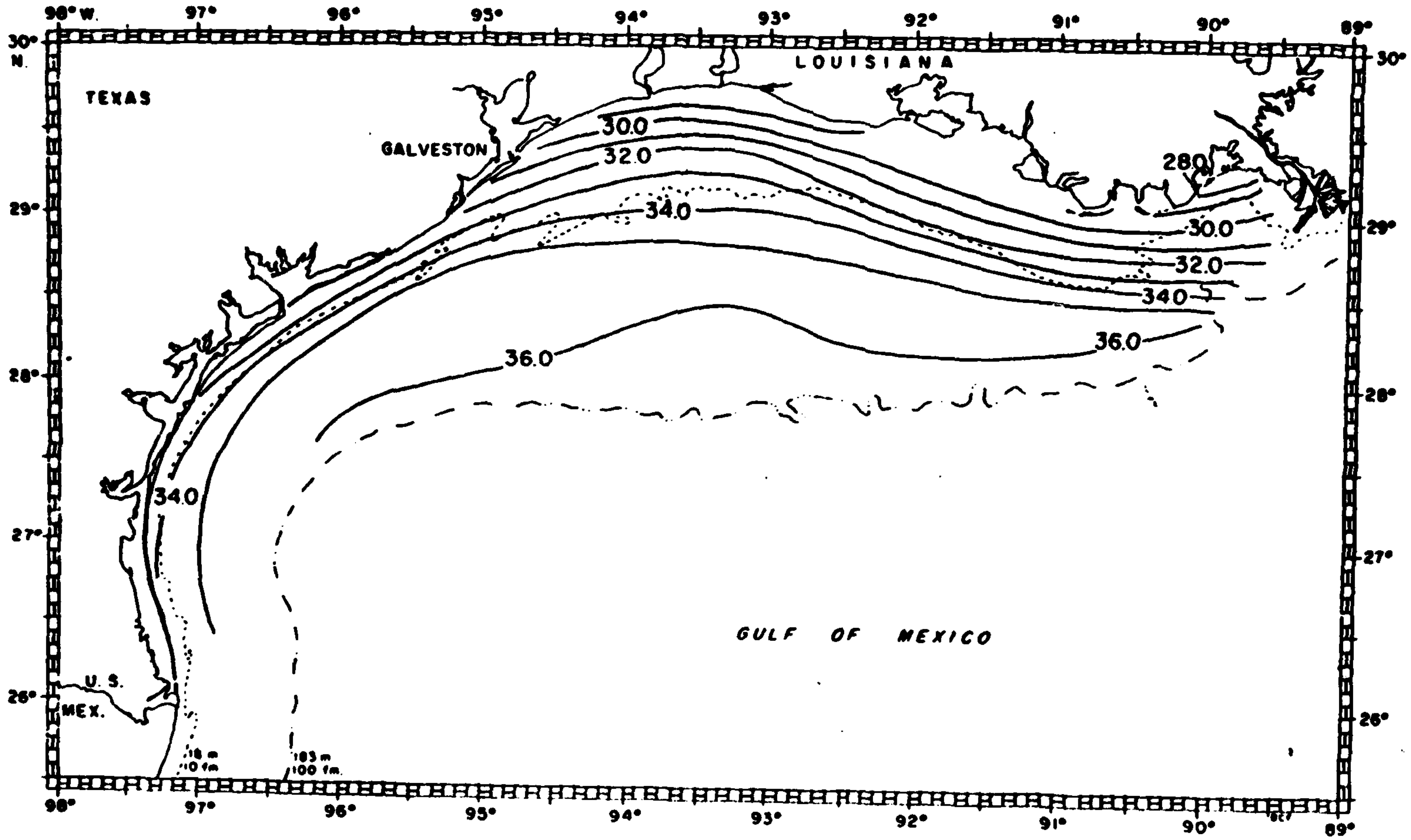
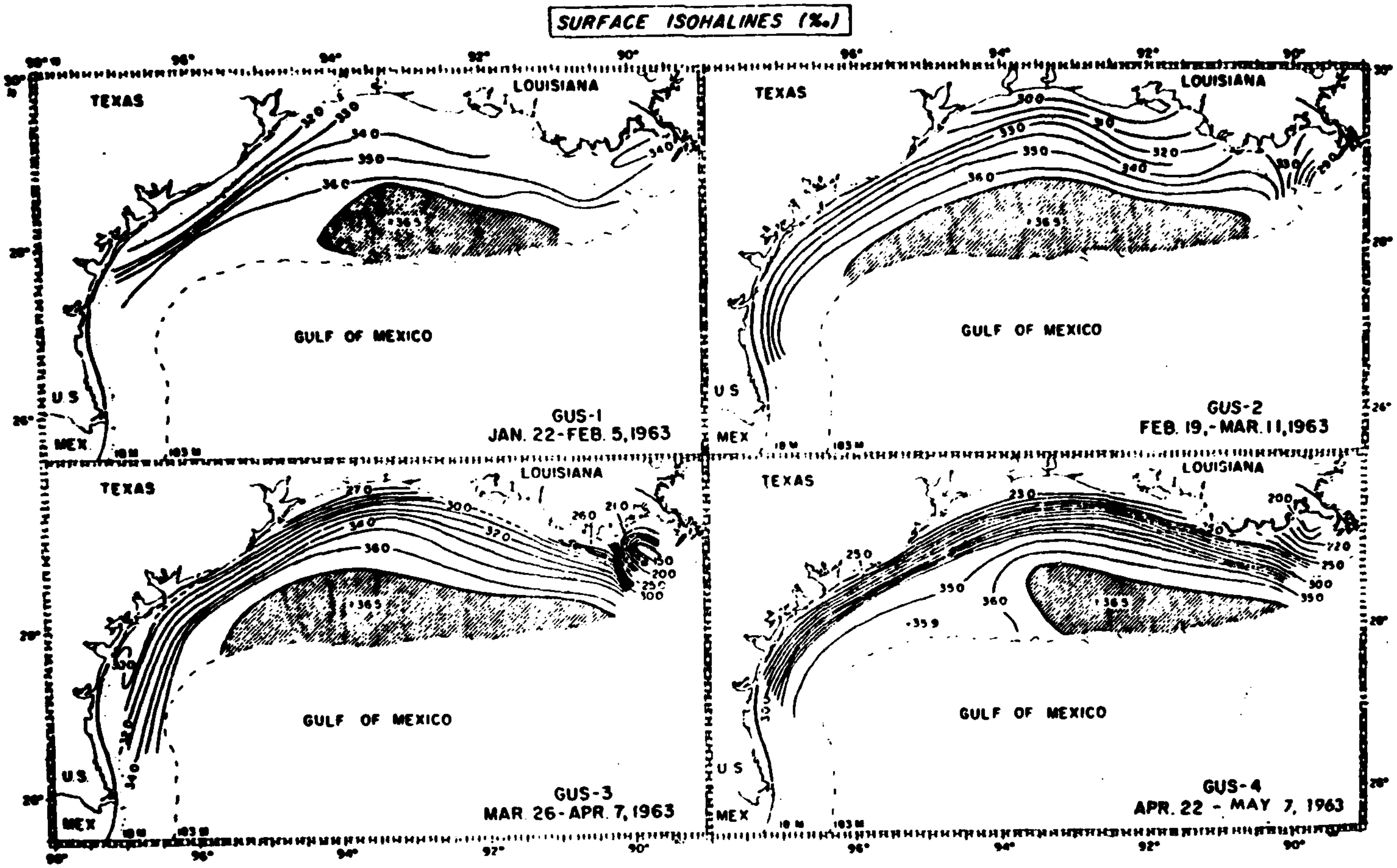


FIGURE A–20 GENERALIZED GROSS LITHOLOGY OF OPEN GULF SEDIMENTS



Salinities (ppt) for the Years 1963-1965 (after Harrington, unpublished MS)

FIGURE A–21 DISTRIBUTION OF AVERAGE SURFACE SALINITIES IN THE NW GULF



Salinities in ppt. (after Harrington, unpublished MS)

FIGURE A–22 AVERAGE SURFACE SALINITIES BY SEASON, JANUARY TO MAY

Following marked seasonal changes in wind stress, which may begin from late March to May, salinities on the shelf begin to rise as a result of entrainment of offshore water as the westward-flowing, longshore current of winter reverses and moves eastward (see section on Currents). At this time, salinities over the shelf from beach to shelf break average about 36.5°/oo from Port Isabel to Galveston and no lower than 34°/oo from there to Sabine Pass (Figure A-23).

c. Temperature. – Four horizontal temperature gradients occur in the surface waters over the continental shelf of the northwestern Gulf. These comprise part of the basis for separating the shelf hydrobiological zones.

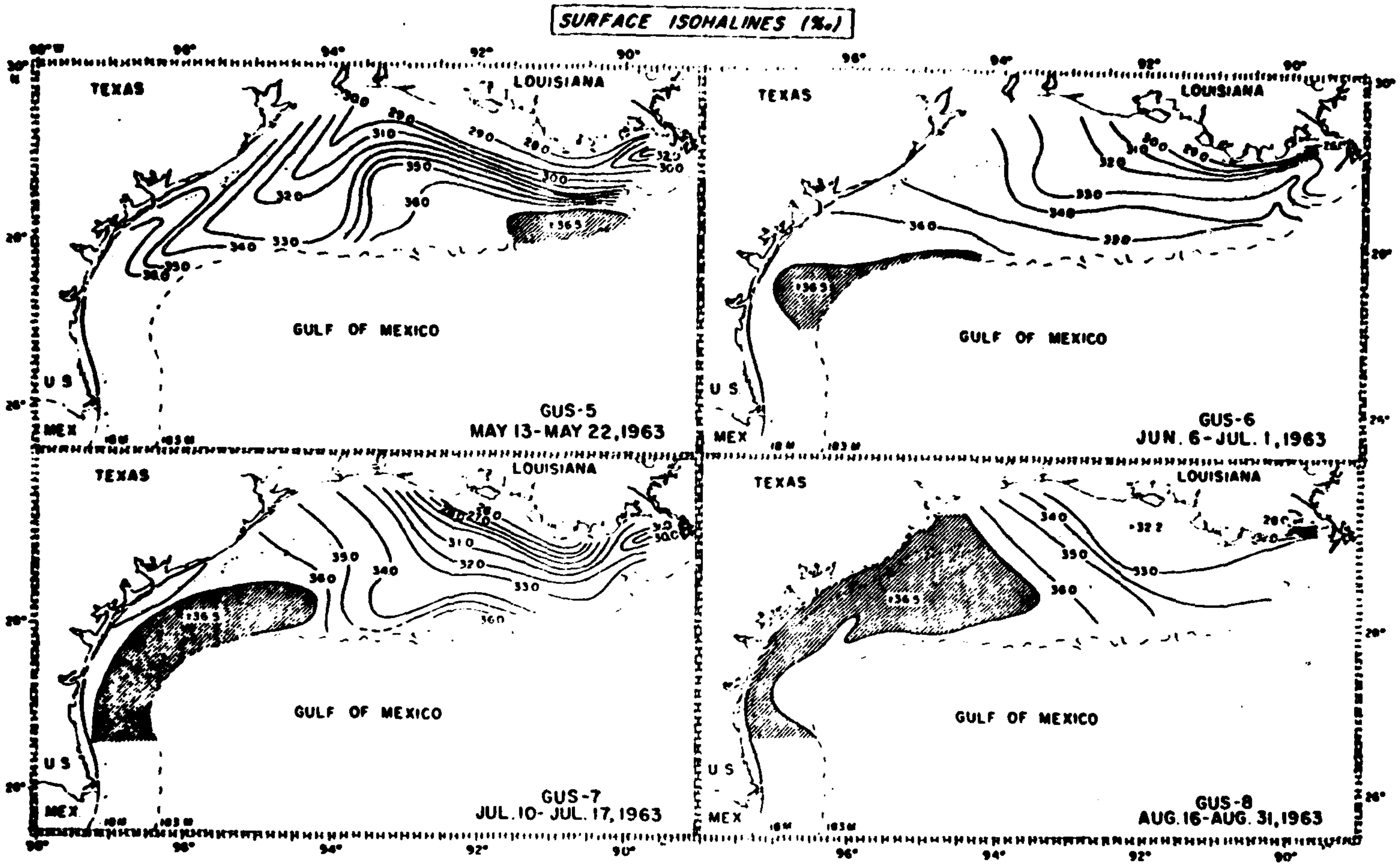
1. On a line normal to shore, winter water temperatures rise from the nearshore to the outer shelf zone. For example, in January 1964, the lowest temperature recorded just off Freeport, Texas (western end of Zone XI) was 9°C, while at the same time it was 19°C at the outer edge of the shelf (Zone XXII) (Figure A-24A).

2. On the same line, but in summer, a reverse gradient is observed, although it is not as marked as that of winter. In August 1963, for instance, the highest temperature just off Freeport was 31.5°C, while at the same time it was 29.8°C along the outer shelf edge (Figure A-24B).

3. Along a line paralleling the coast from off Port Isabel in the south to Sabine Pass in the northeast, the winter surface water temperature drops on the average from 6°C (0.5-9°C), whereas in summer it rises about 2°C from 29 to 31°C (Figure A-24).

4. The above gradients are reflected in the difference in seasonal temperature range off Port Isabel and Sabine Pass. The range in surface water temperature between the highest of summer and lowest of winter, in the years 1963 to 1965, was only 16°C off Port Isabel and in excess of 20°C at Sabine Pass (Figure A-25).

The seasonal changes in temperature-depth structures for the northwestern shelf of the Gulf are well shown along a line extending normal to shore from West Bay (Galveston) to the shelf break (across Zones XI, XXI, and XXII) (Figure A-26). The annual vertical temperature regime is divisible into a period of isothermicity and an equally distinct period of thermal stratification. The relative durations of these periods vary markedly with depth changes. Thus, the isothermal period persists about 9 months in the nearshore shelf zone (Zone XI), but gradually shortens, with increasing distance from shore and increasing depth, until it is virtually absent at the shelf break (65 or so km) (Zone XXII). The periods of thermal stratification are, of course, just the opposite of the above. Hence thermoclines are most pronounced in April and May near shore (Zone XI), in June and July at depths of the intermediate shelf region (Zone XXI), and from May through September on the outer shelf (Zone XXII). Intrusions of cold water along the bottom which are associated with



Note reflection of current reversal in isohalines of May 13 to 22. Salinities in ppt. (after Harrington, unpublished MS)

FIGURE A–23 AVERAGE SURFACE SALINITIES BY SEASON, MAY TO AUGUST

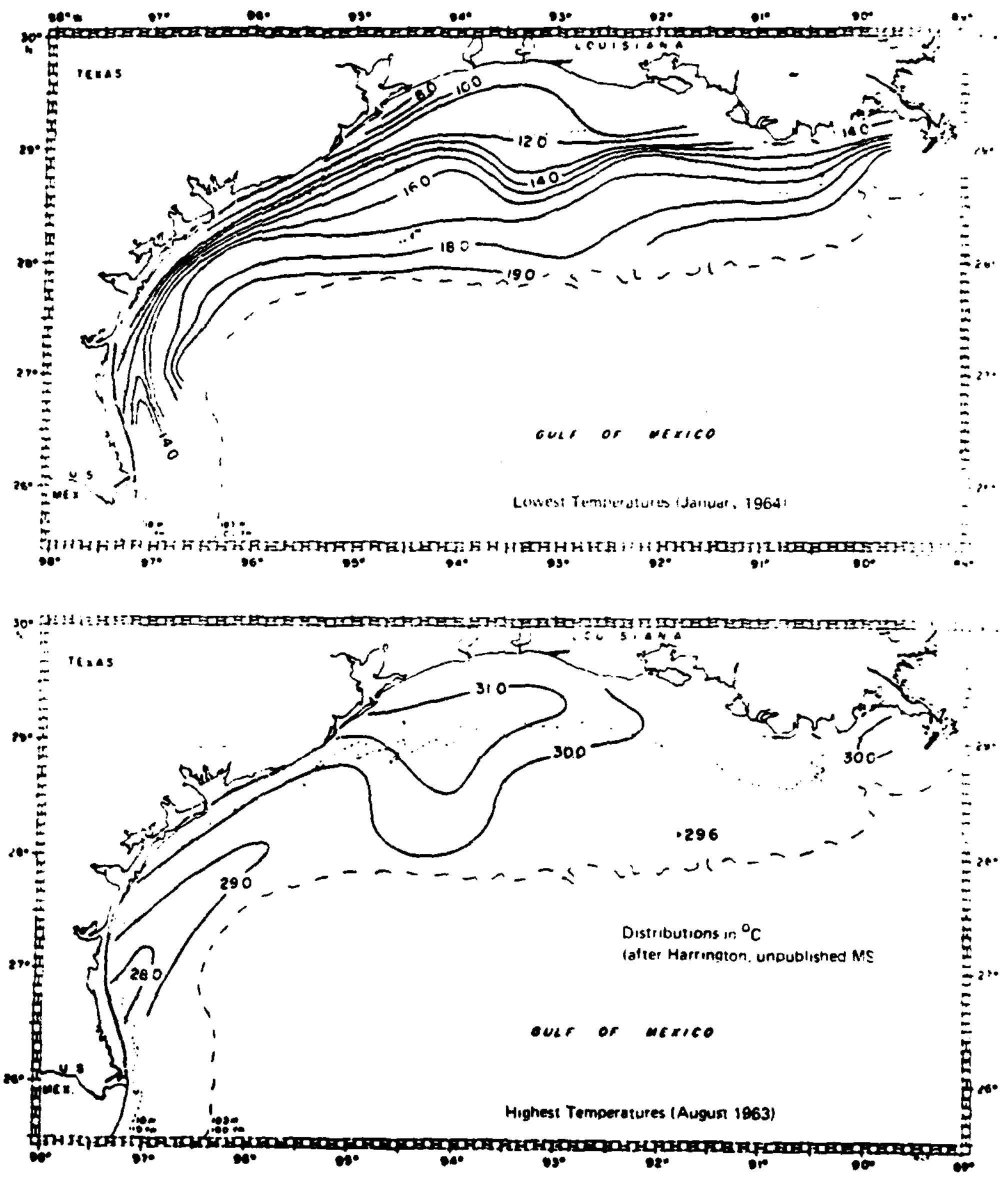
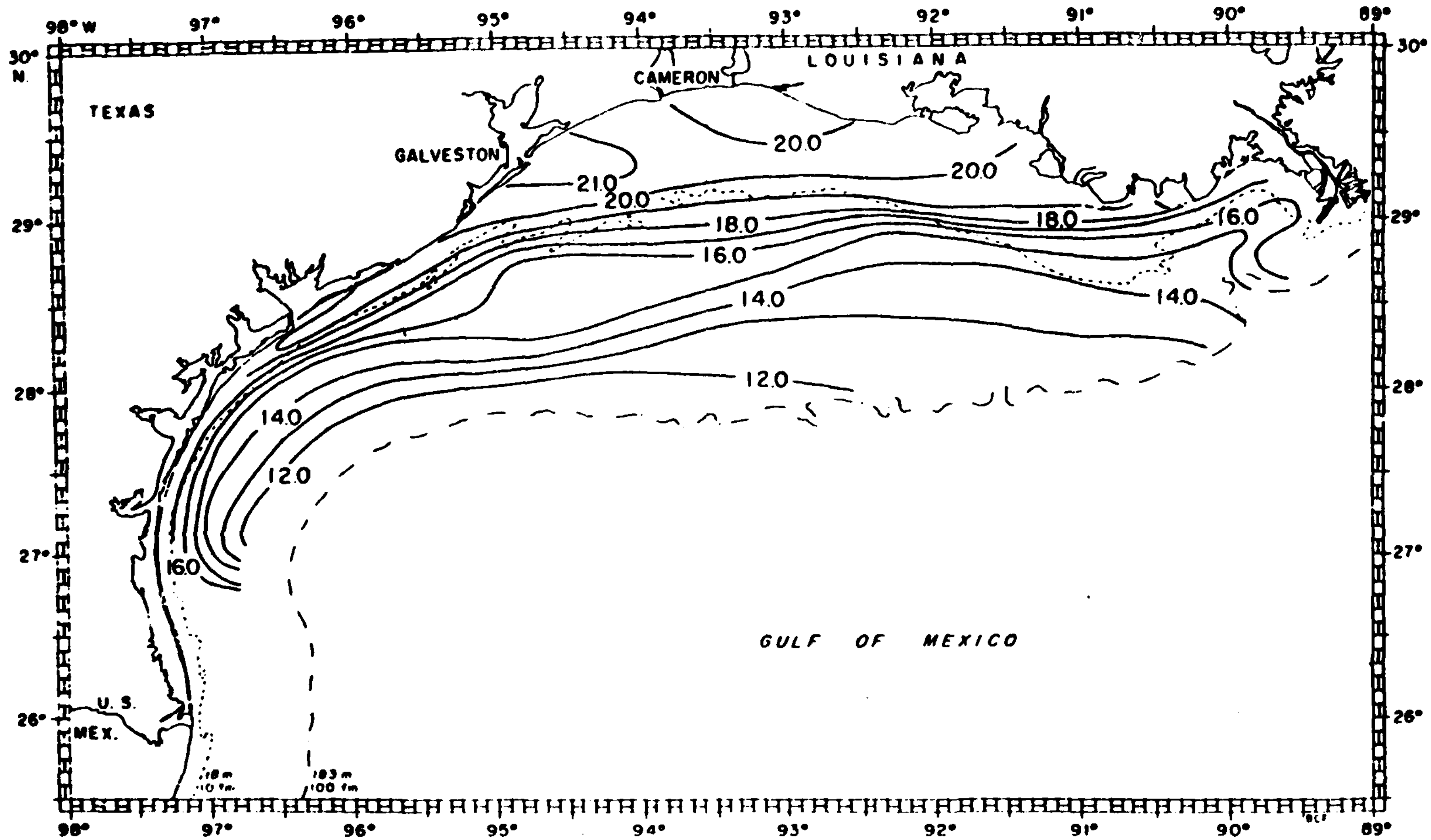
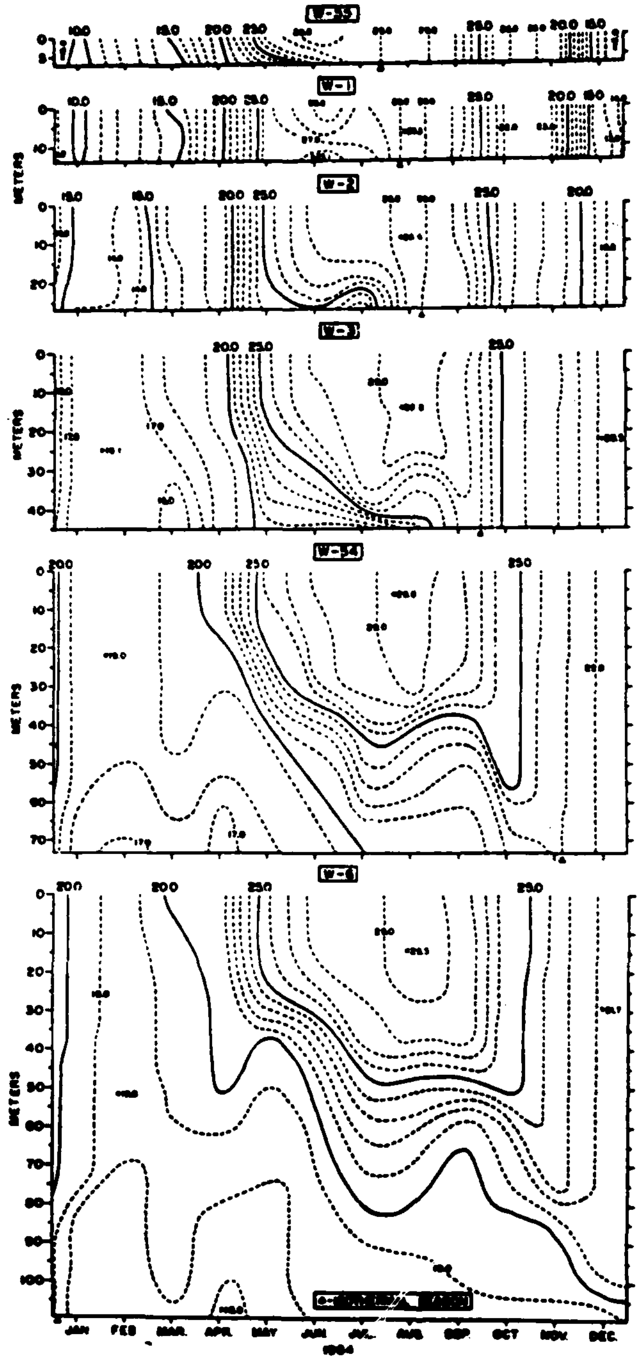


FIGURE A–24 LOWEST AND HIGHEST SURFACE WATER TEMPERATURES IN THE NW GULF



(1963-1965 Isotherms are based on the differences between highest and lowest temperatures (°C) recorded at any one station.) (after Harrington, unpublished MS)

FIGURE A–25 TEMPERATURE RANGES IN SURFACE WATER OF THE NW GULF



The seasonal progression (°C) along a transect off San Luis Pass, Texas in 1964. (after Harrington, unpublished MS)

FIGURE A–26 TEMPERATURE-DEPTH STRUCTURES OFF SAN LUIS PASS, TEXAS

an upwelling caused by northeastward currents in spring and summer (see section on Currents), intensify temperature gradients and lead to stratification.

d. Currents. – Even though current regimes over the continental shelf of the northwest Gulf have not been studied synoptically, enough data are available to provide a general picture of surface-water movements throughout the year.

On the basis of his study of the effects of winds and wind stress on Gulf waters. Franceschini (1953) concluded that the northwest quadrant is an area of surface water convergence. There is, however, a very marked seasonal movement of this accumulation along the coast, which may be related to variations of wind stress over the Gulf as a whole. Franceschini (1953) observed that during the summer (April to August), when the wind stress is generally easterly (Figures A-27 and A-28), the center of convergence moves north and east, paralleling the Texas coast, and reaches its extreme position near the Sabine Pass in July (Zone XI). As noted above, this movement has marked effects on salinity and temperature conditions over the shelf. When the wind stress becomes more northerly in fall and winter (September to March), this center moves south and west, reaching its southern extreme in February off Mexico somewhere between Tampico and the Rio Grande. Obviously this shift and counter-shift of the convergence is caused by major changes in the circulation off Texas (Figures A-29 and A-30).

Drift bottle studies conducted on the NW shelf of the Gulf by Kimsey and Temple (1963 and 1964) and by Watson and Behrens (1970) support the contention that the surface circulation in the entire western Gulf is primarily wind driven. Harrington (unpublished MS) summarized the most important findings of the above drift bottle studies, as follows:

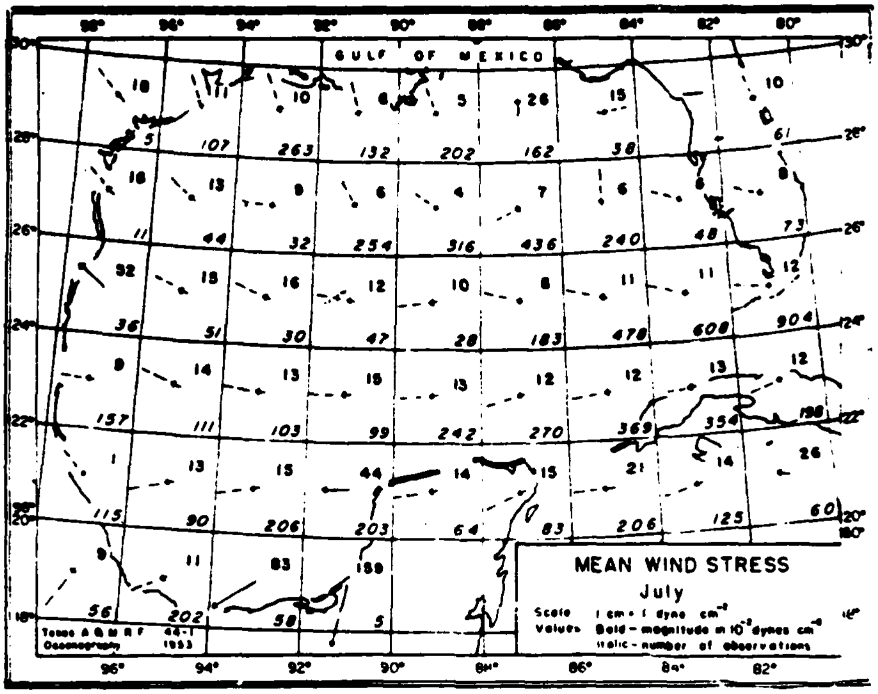
1. Currents between September and April are primarily *westward* along the Louisiana-Texas boundary and thence *southwestward* along the Texas coast (Figure A-31).

2. A reversal of the above system occurs in May or June (it may start as early as the last week of March in some years), and for a short time currents are irregular and then *directly onshore* for a time.

3. But by July the longshore currents along the Texas shelf are flowing strongly northeasterly and thence easterly along east Texas and western Louisiana (Figure A-32).

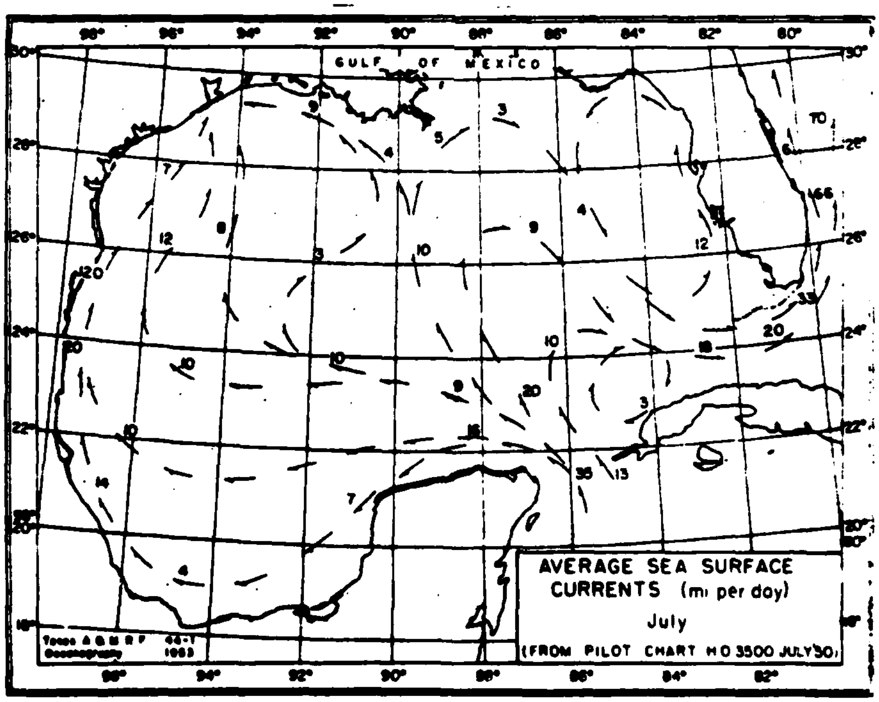
4. By mid-August, however, the rather short-lived easterly flow has subsided, and the longshore movement has once again returned to a westward mode.

To this summary should be added the observations made by Kimsey and Temple (1964) that in winter the west-flowing current moved about 11 miles per



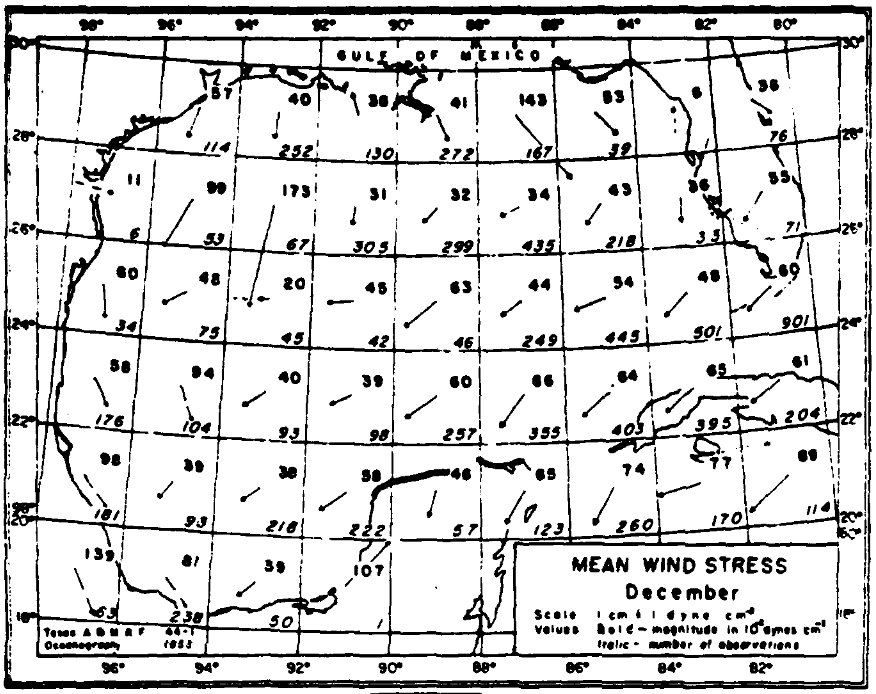
(after Franceschini, 1953)

FIGURE A–27 MEAN WIND STRESSES OVER THE GULF



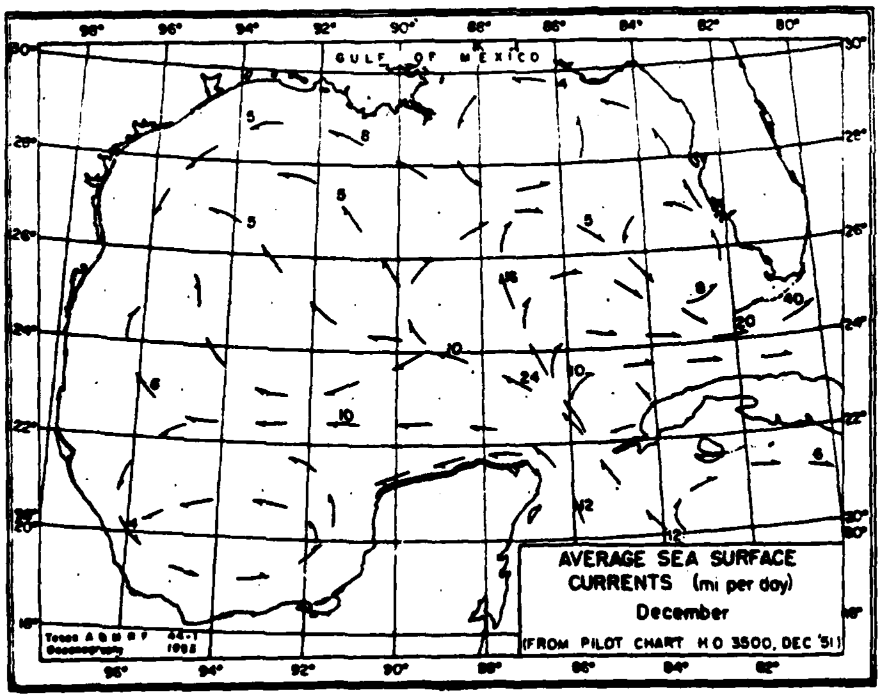
(after Franceschini, 1953)

FIGURE A–28 AVERAGE GULF SURFACE CURRENTS



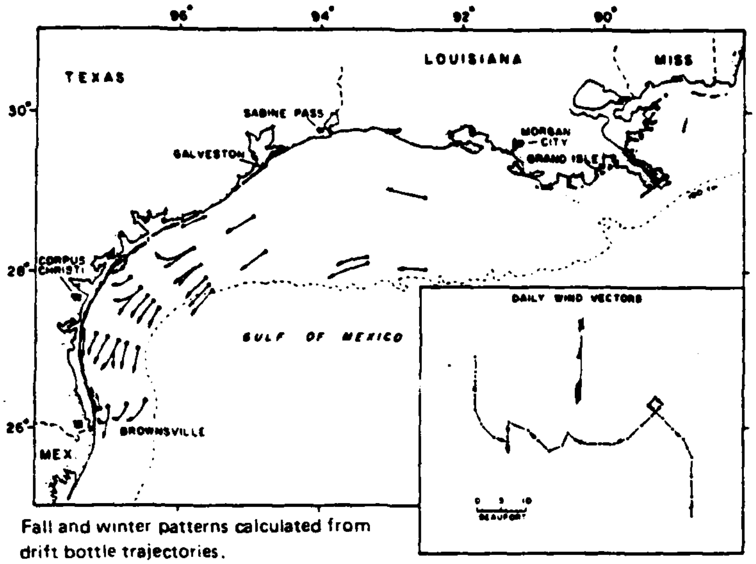
(after Franceschini, 1953)

FIGURE A–29 MEAN WIND STRESSES OVER THE GULF



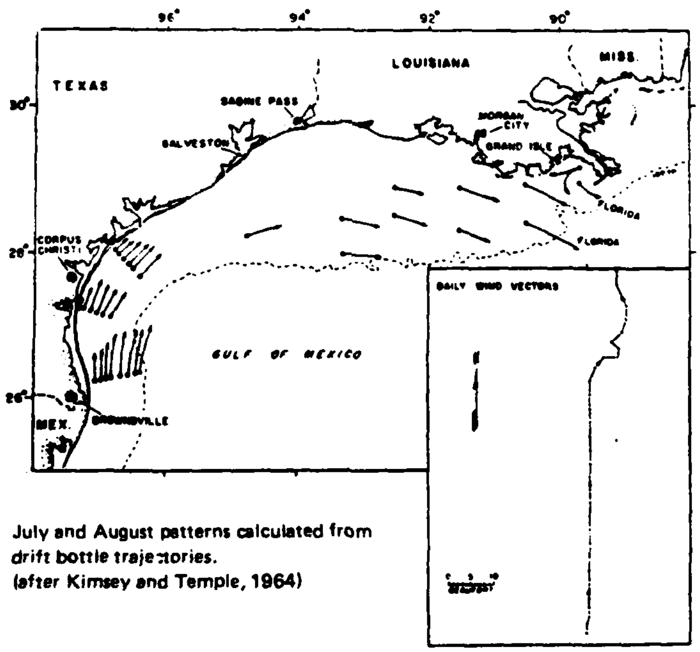
(after Franceschini, 1953)

FIGURE A–30 AVERAGE GULF SURFACE CURRENTS



Fall and winter patterns calculated from drift bottle trajectories.
(after Kimsey and Temple, 1964)

FIGURE A–31 FALL AND WINTER LONGSHORE CURRENT PATTERNS OFF THE TEXAS COAST



July and August patterns calculated from drift bottle trajectories.
(after Kimsey and Temple, 1964)

FIGURE A–32 SUMMER LONGSHORE CURRENT PATTERNS OFF THE TEXAS COAST

day (ca 0.3 kts). They reported, also, that two nearshore countercurrents (1.5 mi. offshore, where water is 7.5 fm deep) were observed in February 1962 when the westerly flow offshore was strong. One longshore countercurrent with a speed of about 0.2 kt was observed off Port Isabel (Zone IX) and the other was measured at 0.1 kt just south of Corpus Christi (boundary of Zones IX and X). Neither current was detected more than a mile and a half offshore.

The convergence discussed above causes some downwelling near shore (Zone XI). This is shown in Figure A-33 (cf. May 12-26) by the down slope of the isotherms. On the other hand, when the offshore currents are flowing to the east, surface waters tend to move offshore and upwelling takes place along the coast (cf. July 9-19 in Figure A-33). This explains in part the anomalous low temperatures of the southwest coast of Texas in summer.

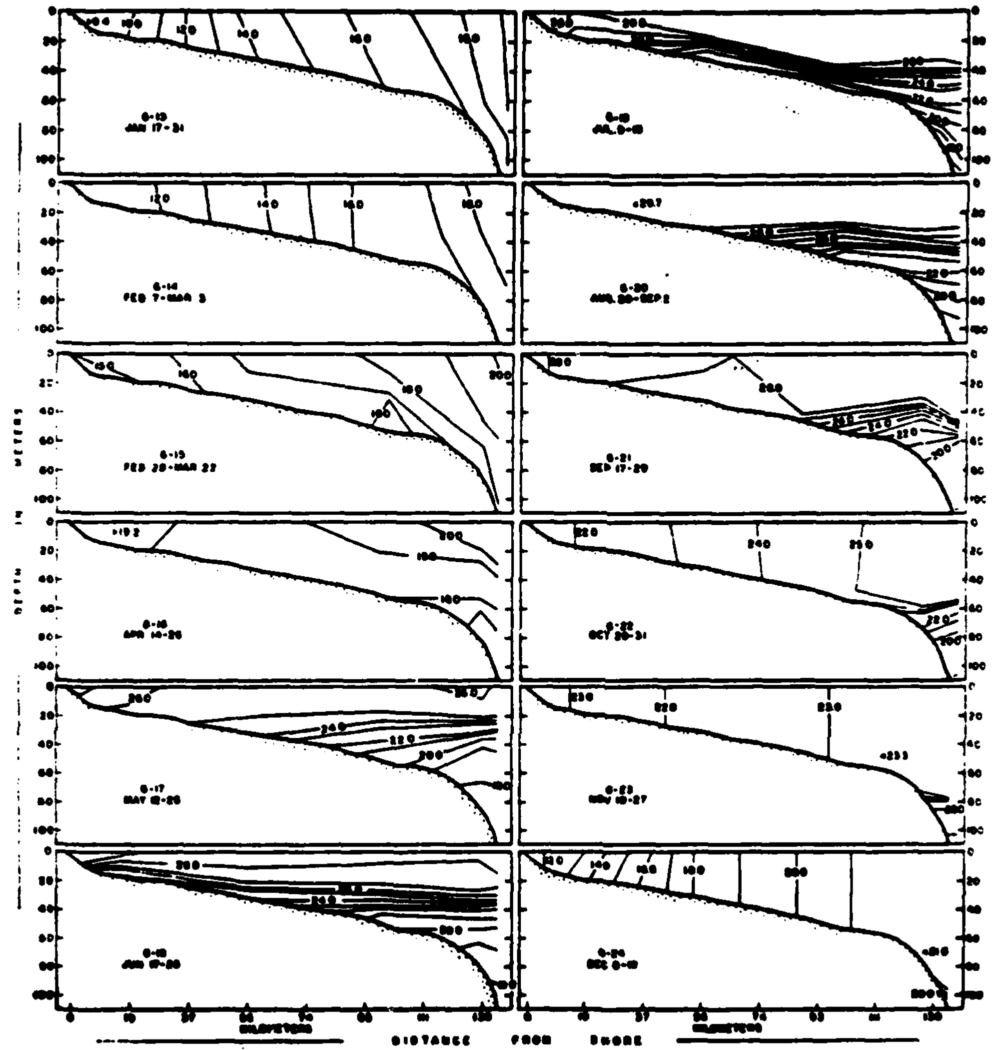
The eastward influence of the current reversal extends great distances, and in fact may entrain large volumes of Mississippi River water carrying it far eastward of its normal path. Kimsey and Temple (1964) report that some drift bottles released in the northeasterly current off central Texas were beached on the Florida east coast in August. One of us (W. Pequegnat) has observed Mississippi River water over the shelf off Panama City, Florida in July and August.

We are fortunate to have been given access to additional drift-bottle data gathered by Bowman and Alderdice (unpublished MS). Bottles were set adrift from the West Flower Garden Bank (27°55'N, 93°48'W, in Zone XXII) at intervals during October 1971 and the first six months and September of 1972. The patterns of recovery are quite instructive:

Release Month	Recovery Sites
January	Port Isabel
February	Matagorda Island, Port Isabel
March	Matagorda Island, Port Isabel
April	Matagorda Island
May	Freeport to Matagorda
June	*Galveston to Cameron, Louisiana*
September	Freeport
October	Matagorda to Port Isabel

Unfortunately no bottles were released in July and early August to confirm the June releases. Even so the fact the June bottles are the only ones that landed in the sector directly inshore from and east of the release site corroborates the existence of the easterly shelf flow at this point.

e. Winds. – An understanding of the characteristics of wind fields over the shelf in the northwest quadrant of the Gulf is a *sine qua non* of an intelligent site-selection process for a deep-water port. More than any other single factor winds in the NW Gulf will determine where spilled oil will go and how fast it will get there. Moreover, wind may even be important as a cause of oil spillage in the first place, through its influence on the behavior of ships, moorage, and waves.



(1964, after Harrington, unpublished MS)

FIGURE A–33 VERTICAL TEMPERATURE STRUCTURE OFF SAN LUIS PASS, TEXAS

The results of collating monthly wind speed and direction data for the Texas coast are presented in Table A-9. The annual average wind speeds are remarkably similar, varying only from 10.2 to 11.9 mph. and the range of monthly averages is equally small (from 4.3 to 7.0 mph). There are some differences in prevailing wind direction that may be important, such as the fact that at Galveston and Port Arthur north winds prevail for one or more months in winter whereas they do not at Brownsville and Corpus Christi. Even so the annual prevailing wind direction at all four stations falls in the small (45°) sector defined by S-SSE-SE.

TABLE A-9

MEAN WIND SPEED (S) IN MILES PER HOUR AND PREVAILING DIRECTION (PD)
(Port Arthur)

ZONES –	Brownsville (I,IX, & XX)		Corpus Christi (II,X, & XXI)		Galveston (II,X,&XXI)		Port Arthur (III & XI)	
Month	S	PD	S	PD	S	PD	S	PD
J	11.8	SSE	11.9	SSE	12.2	SE	11.4	N
F	12.5	SSE	12.9	SSE	12.0	SE	12.1	S
M	13.7	SE	14.0	SSE	11.8	SE	12.2	S
A	14.4	SE	14.3	SE	11.7	SE	12.4	S
M	13.8	SE	13.1	SE	10.8	SE	10.8	S
J	12.7	SE	12.1	SE	9.8	SE	9.0	S
J	11.8	SE	11.7	SSE	8.7	S	8.1	S
A	16.8	SE	10.9	SSE	8.5	S	7.6	S
S	9.8	SE	10.1	SE	11.0	E	8.8	NE
O	9.8	SE	9.9	SE	11.9	E	9.1	N
N	10.9	SSE	11.2	SSE	12.8	E	10.5	N
D	11.0	NNW	11.1	SSE	12.9	N	10.9	N
Yr	11.9	SE	11.9	SSE	11.1	SE	10.2	S

(compiled from Brower et al., 1972)

It is, therefore, instructive to study the percentage frequency of wind direction and velocity. Since the above four stations were so similar, only two of them were selected for further analysis. Corpus Christi was selected for two reasons, which are (a) because it lies on the line between Zones I and II, and (b) because it has no months in which northerly-component winds prevail. Galveston was picked because it does have at least one month when north winds (offshore) prevail, and because it lies near the line separating Zone II from Zone III. These frequency data are listed in Table A-10. It is apparent that:

1. The most frequently occurring wind direction at both stations is onshore from the SE and that the other high frequency directions array themselves equally on each side of SE, i.e., E-ESE-SE-SSE-S at both stations.

2. Winds can be expected to blow from the above quadrant (90°) 61 percent of the time at Corpus Christi and 55 percent at Galveston.

3. Table A-10 also shows that the fastest winds, other than those associated with hurricanes, are offshore winds having some north-component.

TABLE A-10

FREQUENCY ANALYSIS OF WIND SPEEDS AND DIRECTIONS FOR EACH 22.5 DEGREE SECTOR CENTERED NEAR CORPUS CHRISTI AND GALVESTON

	Corpus Christi Region		Galveston Region	
Wind Direction	Percent Frequency	Mean Speed (mph)	Percent Frequency	Mean Speed (mph)
N	7.8	19.5	7.4	16.4
NNE	4.9	17.4	4.2	15.8
NE	7.3	14.3	8.2	14.3
ENE	4.6	13.7	4.7	14.4
E	10.9	12.1	11.8	12.9
ESE	8.8	13.7	7.8	12.8
SE	19.3	13.9	15.8	12.8
SSE	11.3	15.0	8.5	13.4
S	11.1	13.9	11.0	12.2
SSW	2.4	13.1	3.2	11.9
SW	1.9	11.3	3.3	10.6
WSW	0.6	11.1	1.4	10.6
W	1.3	11.2	2.7	11.5
WNW	0.9	14.3	1.7	13.9
NW	2.5	16.4	3.3	15.3
NNW	2.5	18.7	2.3	16.8

(after *Synoptic Meteorological Observations, North American Coastal Marine Areas*, Vol. 6)

Franceschini (1953) indicates that although the Gulf of Mexico is small, and its currents are modified to some degree by coastal contours and bottom configurations, its surface circulation is in part a result of the wind stress. For practical purposes the stress of the wind on a water surface may be determined from wind velocity data, the assumption being that stress (in dynes cm^{-2}) is proportional to the square of the wind speed. Whereas in deep water the surface wind current is directed at some large angle from the wind direction, in shallow waters there is bound to be a rather small deflection angle between the wind and the induced current. This is particularly true in coastal areas where water is restricted to motion parallel to the coastline. The deflection angle here may be 5° or less. Indeed, as Franceschini (1953) states: "When the stress is parallel to the coastline, the resulting surface currents are in the direction of the stress."

f. Unusual Tides and Storm Surges. – In the Gulf of Mexico tidal action is damped and the range of tides is reduced to an average of about two and a half feet. Along much of the Texas coast the tides are of the daily type. As Marmer (1954) states, the most prominent variation in range of tide in the daily type is the fortnightly change associated with the moon's declination. When the moon is near its maximum declination, the range of tide in the daily type is greatest and the tides are called *tropical tides;* when the moon is over the equator, the tide has the least range, and these tides are called *equatorial tides.* It is at this time that there may be several days when two high and two low tides per day will occur. Even though the Gulf tides have small daily and seasonal ranges, they do play important roles in modifying currents and accelerating the movement of water through narrow passages. It is, however, the storm tides and surges that have the greatest impact on the open coast of the Gulf of Mexico.

Collier and Hedgpeth (1950) report that tides of 16 feet on the southwest Texas coast are not unusual with the passage of hurricanes many miles away. Hurricane *Camille* (1969) is reputed to have caused a tide of 30 feet at Long Beach, Mississippi (to the right of the storm) when it made landfall near Pass Christian, Mississippi several miles to the west. There is no basis for assuming that such severe storms as *Camille* (winds in excess of 200 mph) will not strike the Texas coast. It is, however, more instructive to present purposes to observe normal wave patterns and then compare these with storm conditions.

Table A-11 presents a general summary of the percentage occurrence of various wave heights for the entire Gulf. It is apparent from this that waves over 5 feet in height will occur about one day in four during fall and winter and only one day in ten during summer.

TABLE A-11

PERCENTAGE FREQUENCY OF WAVE HEIGHTS IN THE GULF OF MEXICO

Wave Height (feet)	Season				
	Winter	Spring	Summer	Fall	Average
10 or more	2	1	1	1	1
5 – 10	23	14	9	24	18
2 – 5	45	45	40	45	44
2 or less	30	40	50	30	37

(from Climatological and Oceanographic Atlas for Mariners)

Somewhat more instructive is the specific information given above wave structure at Galveston, Texas. Short period waves (7 sec. or less) and wave heights of less than five feet predominate here (Table A-12).

TABLE A-12

SPECTRUM OF WAVE PERIODS AND HEIGHTS IN PERCENT OCCURRENCES FOR GALVESTON BEACH

Period (sec.)	Height in Feet					
	1 – 2	3 – 4	5 – 6	7 – 9	10 – 11	12 – 16
5 or less	20.7	25.9	9.0	4.0	0.2	0.2
6 – 7	2.0	5.7	10.5	7.1	0.0	0.2
8 – 9	0.8	0.5	1.6	2.6	0.6	0.5
10 – 11	0.6	0.3	0.0	0.9	0.2	0.0
12 – 13	0.0	0.2	0.0	0.0	0.0	0.0
14 or more	0.0	0.3	0.2	0.0	0.0	0.0

(from Summary of Synoptic Meterological Observations, North American Coastal Marine Areas, Vol. 6)

Studies indicate that the highest waves resulting from hurricanes will in all probability reach the coast about two hours before the storm. The tidal bore, on the other hand, arrives with the intensity period of the storm. This combined surge and wave action stirs up the sea bed and transports the soil inland with the flood.

In Figure A-5 we saw the frequency of occurrence of hurricanes in various sectors on and off the Texas and Louisiana coasts. We note a definite trend in the years from 1900-1956 for fewer of these storms to occur in Zones I and IX than in

the more northeasterly Zones II, III, X and XI. The same trend appears to apply to offshore regions as well.

In the present study the wave characteristics and frequency of-occurrence at offshore positions are of considerable importance. Data derived from two stations on the 100-fathom isobath, one off Brownsville and the other off Galveston (Zone XXII), show the following points (wave heights for significant waves).

g. Brownsville

1. All hurricanes approach in the sector from ENE to SE, but are most frequent and most intense along a line slightly south of east.

2. Wave heights of 25 feet at 100 fathoms can be expected once very 10 years.

3. Once every 10 years waves with periods of 16 seconds can be expected.

4. Wave heights of 40-50 feet can be expected only once every 100 years and they will have periods of about 18 seconds.

h. Galveston

1. Hurricanes tend to approach in the sector from ESE to S, but are most frequent from the southeast.

2. Wave heights of 25 feet at 100 fathoms can be expected every 3.5 years.

3. Once every 10 years waves with periods of 16 seconds can be expected.

4. Wave heights of 55-60 feet can be expected only once every 100 years and they will have periods in excess of 18 seconds.

2. Geology

a. Sediments. – The continental shelf of the northwest Gulf of Mexico is a smooth, gently sloping and sediment-covered plain that is interrupted by occasional hills or banks and by strings of coral heads in 6-8 fathoms of water (western end of Zone XI) off Freeport (Mattison, 1948) and in 30-40 fathoms (Zone XXII) off Corpus Christi (Smith, 1948). The width to the shelf break at 65 fathoms varies from 50 miles in the northwest to 100 miles in the northeast.

Recent sediments are divisible primarily into nearshore sands and shelf facies muds (silty clays and clayey silts). Extensive areas are covered by alternating sands and muds (Figure A-18). The basal sands are exposed at the surface near the shore line and across most of the shelf off the Rio Grande (across Zones IX and XX), and much of east Texas and western Louisiana (across Zones XI and XXI), although here there tends to be more alternation of sands and muds. The shelf facies overlies the basal facies off central Texas, particularly in a band running from Freeport to Aransas. The importance of this lithological feature to the Texas shrimp fishery is discussed in a later section.

Texturally about half of the surface sediments on the shelf are polymodal mixtures of thin overlapping sediment masses (Curray, 1960). The mixing has been by burrowing organisms and the strong wave surges associated with hurricane waves. Most of the sand-sized particles in the outer shelf silty clays are foraminifera and echinoid fragments (Curray, 1960). Glauconite is locally abundant in the relict basal sands of the outer shelf.

As might be expected from the earlier discussion of currents the waves and currents generated by the south to southeast winds produce a net littoral transport from northeast to southwest along the upper coast, and from north to south along the lower coast. But, as mentioned earlier, reversals of currents and countercurrents, and thus net littoral transport, do occur in later spring and summer. The general littoral movements of beach and shore materials along the shore are interrupted by tidal currents through passes into the lagoons and by jetties and groins. Major natural passes exist at Sabine Pass, Bolivar Roads (Galveston), San Luis Pass (West Bay) (Zone XI); Pass Cavallo (Matagorda Bay), Aransas Pass (Corpus Christi Bay, etc.) (Zone X); and Brazos Santiago Pass (Zone IX) into Lower Lagune Madre (Zone I). Four of these have been deepened (Sabine, Bolivar, Aransas, and Brazos Santiago) and provided with lengthy stone jetties. Jetties are are also in place opposite old Brazos River entrance, Matagorda Ship Channel, and Port Mansfield Channel through Padre Island. The natural and man-made passes and channels disrupt the normal longshore drift by increasing the deposition adjacent to and in the passes. All of the navigation entrances are dredged regularly by hopper dredge and the spoil dumped at sea.

Other factors affecting the rate and volume of littoral transport are the sediments carried to the Gulf by the major rivers along the coast and the longshore currents affecting movement within the littoral zone. Along the upper coast, the Sabine, Neches, and Trinity rivers carry mostly fine sediments and dump much of it in estuaries. Hence they don't supply much sand to the beaches and shore. On the other hand the Brazos, Colorado, and Rio Grande rivers carry larger percentages of sandy sediments and they empty directly into the Gulf. Hence they contribute much sand to the Gulf, especially when at flood stages.

b. Banks and Topographic Highs. – Shepard (1937) suggested that some of the shelf-edge banks represent the surface expression of salt domes. Some of the more interesting of these are the Claypile Bank (Zone XXII) and West Flower Garden

Bank (Zone XXII) (Figure A-19). The organic cap of the latter consists of various corals. Dr. Thomas Bright is presently studying these features and has provided TerEco Corporation with a great deal of information about these banks. Much of the following description is based on his as yet unpublished studies.

In the near vicinity of the West Flow Garden Bank (Zone XXII) there are 63 submerged topographic highs that extend two or more fathoms above the surrounding bottom and crest at depths less than 100 fathoms (Figure A-20). The majority of these banks occur seaward of the 50-fathom isobath in two linear groupings. The first group forms a broad arc starting southeast of Brownsville and terminating near the Mississippi Delta (Zone XXII). Its banks are widely spaced and occur within the 25- and 45-fathom contours. The banks of the second group are closely packed and extend from 95°00′ west longitude to the Mississippi Delta between 50 and 200 fathoms (Zone XXII and northern part of Zone XXVII). The latter group is only half of a series of banks that continues out to the 600-fathom line (Zone XXVII) (see Carsey, 1950).

Closer to shore a number of reeflike structures of low relief have been reported off Padre Island (Zone IX) in depths less than 20 fathoms (Williams, 1951; Tunnell and Chaney, 1970). Another feature is Heald Bank off Galveston in less than 10 fathoms (Zone XI). Sharp drop-offs, referred to by fishermen as shell ridges, occur all along the Texas coast at the 10-fathom isobath (Zones IX, X, and XI). Virtually all of the above features have some importance to commercial and sports fisheries along the coast, as will be mentioned later.

In addition to their fisheries relationships, some of these banks are of considerable scientific value. Principal among these are the West Flower Garden and East Flower Garden Banks (Zone XXII). The former has been studied intensively during the past two years (Edwards, 1971 and Bright and L. Pequegnat, in press). This bank is located 107 nmi south of Galveston and is believed to be the northernmost thriving tropical, shallow-water coral reef in the Atlantic Ocean with the exception of Bermuda. The Flower Garden rises to within 10 fm of the surface and its upper surface down to 25 fm is covered by 80 acres of a *Diploria-Montastrea-Porites* coral reef community.

Over 100 species of *tropical* reef fishes occur at the West Flower Garden and over 50 species of crustaceans (crabs, shrimps, and barnacles) occur there.

Below 25 fathoms on the bank the coral community is replaced by a biostromal bank occupied by what is generally termed the *Gypsina-Lithothamnium* community. At 42 fathoms depth this gives way to an *Amphistegina* sedimentary facies, and at 55 fathoms this is replaced by a quartz-planktonic foraminifer sedimentary facies.

The *Gypsina-Lithothamnion* community is dominated by calcareous algae, but common associates are soft algae, large sponges, polychaete annelids, crustaceans, starfish, crinoids and small fishes.

The flat sandy bottom of the *Amphistegina* facies and the quartz-planktonic foraminifera facies is interrupted between 40 and 50 fathoms by numerous drowned patch reefs, which are probably remnants of Pleistocene or early Holocene reefs. These become more abundant between 50 and 80 fathoms, where they support a very distinctive fauna. This fauna is presently under study by personnel of Texas A&M University and the Flower Garden Ocean Research Center in Galveston (T.J. Bright, personal communication).

It is important to note that coral reef communities are structured by and their integrity is dependent upon the development of a few key species of reef building corals. If these are killed, the community quickly degrades and the dead corals are covered by algae. Recovery in the community, if it ever occurs, is a long time in the making. Some reports indicate that the minimum time is more than 30 years. Harmful factors would be high levels of organic materials having a high oxygen demand (e.g., sewage) and sedimentation, which could increase as a result of dredging.

Sedimentation is a serious threat to the survival of reef corals. Although they can cleanse themselves of moderate amounts of sediment falling from above, most cannot live long if heavily coated (Marshall and Orr, 1931). Corals (especially) killed by siltation in 1941-43 during dredging operations associated with construction of an airfield in Castle Harbor, Bermuda have not been replaced as late as 1972.

3. Chemistry

Two factors of major importance to the chemistry of the western Gulf of Mexico are the low exchange rate with the eastern Gulf's loop current and the westward flow of the Mississippi waters.

Sackett (1972) provides relative values of elemental constituents between Gulf surface waters and Mississippi runoff (Table A-13) This runoff produces well-known salinity gradients and non-oceanic ratios of certain dissolved ionic constituents, in relation to chlorine, that reflect the relative contributions from open ocean and river sources.

Except for very local conditions, dissolved oxygen levels appear not to be a limiting factor for shelf organisms. Averaging about 4.5 ml/l at the surface, dissolved O_2 values may drop to 3.0 ml/l on the shelf (Zones XX, XXI and XXII) and an absolute minimum of about 2.5 ml/l at 275 fathoms (Zone XXVII) (Nowlin and McLellan, 1967). Differences between dissolved oxygen profiles in the eastern and western (large decrease at intermediate levels in the west) Gulf are probably related to increased residence time of water in the west.

In the Gulf of Mexico, most elements show higher values in shelf than in open waters (Sackett, 1972).

TABLE A-13

CONCENTRATIONS OF COMMON ELEMENTS IN SURFACE WATERS

Chemical	Gulf of Mexico Surface Water (ppm)	Mississippi River Surface Water (ppm)
Cl	20,000	13
Na	10,950	11
So_4	2,760	33
Mg	1,410	8
Ca	420	34
K	400	3
HCO_3	140	108
SiO_2	0.06	9
NO_3	(less) 0.01	2
Fe	0.01	0.1

The amount or nature of suspended material in seawater is important to removal by absorption of various dissolved chemicals, and as a substrate for bacterial action. Present data on suspended matter in Gulf waters are presented in Table A-14.

TABLE A-14

MEANS FOR TOTAL SUSPENDED MATTER (TSM) AND ORGANIC SUSPENDED MATTER (OSM) IN THE GULF

	TSM(mg/l)	OSM(mg/l)
Shelf to 100 fm	0.761	0.428
Open Gulf (0-50 fm)	0.194	0.100
Open Gulf (50-2000 fm)	0.166	0.056

(adapted from Sackett, 1972)

Garrett (1967) determined the lipid composition of natural slicks in the Gulf of Mexico and found that the fatty alcohols and fatty acids in the thin surface film were less water-soluble and higher in molecular weight than in waters at one-meter depth. He believes that the surface-active compounds in the slicks can alter the temperature of the sea surface and interrupt the normal mass and thermal convection processes just below the slick.

C. RESIDENT AND TRANSIENT MARINE BIOTA

1. Attached Vegetation

Key Species. – Some 116 species of benthic and attached algae have been reported from the coast of Texas by Humm and Hildebrand (1962), but the majority of these are restricted to waters of the embayments discussed above. The paucity of hard substrata restricts the diversity and abundance of attached algae in the shallow waters of the Gulf proper. Coastal marshes are found in Texas but their extent diminishes rapidly in width southwestward from Port Arthur on the Sabine River. For the most part to the south in Texas this marsh habitat is not only much narrower than in Louisiana but also is replaced by a series of lagoons and bays with offshore bars or islands that are the most continuous in eastern North America (Murray, 1961). Calcareous algal developments on banks have already been mentioned (see section on Geology).

2. Zoobenthos and Ichthyofauna

a. Key Species. – Four faunal assemblages on the continental shelf of Texas are of primary concern to the present study. These are the Nearshore (or Inner Shelf) Assemblage (0-12 fathoms), the Intermediate Shelf Assemblage (12-25 fathoms), the Outer Shelf Assemblage (25-100 fathoms), and the Northern Gulf Calcareous Bank Assemblage. The latter has been discussed under the Geology section; hence only the first three will be described in this section.

b. Nearshore Assemblage. – Some data on the distribution and relative abundance of large benthic invertebrates are given by Darnell (personal communication), Harper (1970), Hildebrand (1954), and Parker (1960). The most abundantly represented species between shore and 12 fathoms appears to be:

Cnidaria
- Renilla

Bivalves
- Dinocardium robustum

Crustaceans (shrimps)
- Penaeus setiferus
- Sicyonia brevirostris
- Sicyonia dorsalis
- Penaeus aztecus

Echinoderms
- Astropecten sp.
- Luidia clathrata
- Mellita quinquiesperforata

Gastropods
- Olivella mutica
- Terebra cinerea
- Pleurobranchia hedgpethi
- Oliva sayana

Cephalopods
- *common*

Crustaceans (crabs)
- Callinectes ornatus
- Hepatus epheliticus
- Libinia emarginata
- Persephone p. aquilonaris

Harper (1970) prefers to group animal communities by the sedimental nature of the bottom and lists the following Nearshore Shelf Assemblage off Galveston (Zone XI):

Sandy Bottom

Gastropods
- Olivella mutica
- Pyramidella crenulata
- Terebra dislocata

Bivalves
- Tellina iris
- Mulinia lateralis

Polychaete Annelids
- Onuphis eremita oculata
- Owenia fusiformis

Crustaceans
- Isocheles wurdemanni
- Ancinus depressus
- Pagurus longicarpus
- Libinia dubia

Echinoderms
- *Mellita quinquiesperforata*

Mixed Bottom

Gastropods
- Terebra protexta
- Acteon punctostriatus

Bivalves
- Abra aequalis
- Corbula caribaea

Polychaete Annelids
- None listed

Crustaceans
- None listed

Echinoderms
- *None listed*

Muddy Bottom

Gastropods
- Volvulella texasiana

Bivalves
- Nuculana concentrica
- Lunarca ovalis

Polychaete Annelids
- Diopatra cuprea
- Sternapsis scutata
- Spiochaetopterus oculatus

Echinoderms
- Micropholis atra
- Hemipholis elongata

Darnell (personal communication) has supplied us with the following list of fishes collected in the Nearshore Shelf region (Zones IX, X, and XI). Percentages are of total individuals of fish species taken in the nearshore subdivision.

Triglidae	**Sciaenidae**
Prionotus rubio 26%	Cynoscion nebulosus 17%
Polynemidae	**Bothidae**
Polydactylus octonemus 11%	Syacium gunteri 5%
	Citharichthys macrops 4%
	Etropus crossotus 3%
Cynoglossidae	**Tetraodontidae**
Symphurus plagiusa 5%	Sphoeroides parvus 5%
Serranidae	**Sparidae**
Centropristis philadelphius 4%	Stenotomus caprinus 3%

The above 10 species account for 83% of the individuals captured. It takes an additional 51 species to account for the remaining 17% of individuals.

c. *Intermediate Shelf Assemblage* (Zones XX and XXII). -- Parker (1960) divides the assemblage living in this zone according to bottom type. He notes that relatively few species occur on the mud bottom at these depths (12-25 fm), but most of those which do are more abundant than those found on sand bottom. Only the more common species are given here.

Mud Bottom

Bivalves	**Gastropods**
Varicorbula operculata	Anachis saintpairiana
Pitar cordata	Nassarina glypta

Sand Bottom

Bivalves	**Gastropods**
Chione clenchi	Distorsio clathrata
Gouldia cerina	Fasciolaria hunteria
Tellina georgina	Murex fulvescens

Darnell (personal communication) has provided us with the results of his collecting in the intermediate shelf (Zones XX and XXII).

Bivalves	**Gastropods**
Chione clenchi	Busycon contrarium
Laevicardium laevigatum	Distorsio clathrata
Ostrea frons	Polystira albida
	Strombus alatus
Crustaceans (shrimps)	**Crustaceans (crabs)**
Penaeus aztecus	Calappa sulcata
Penaeus setiferus	Callinectes ornatus
Sicyonia dorsalis	Porcellana sayana
Trachypenaeus constrictus	Portunus spinicarpus
	Portunus spinimanus

Echinoderms
Astropecten sp.
Luidia clathrata

The intermediate shelf ichthyofauna is diverse but drops considerably in total number of fish species and in degree of dominance. Percentages given after species names are of all fishes trawled in the Intermediate Shelf region.

Bothidae
Syacium gunteri 18%
Citharichthys macrops 15%
Engyophrys senta 3%

Triglidae
Prionotus rubio 8%

Cynoglossidae
Symphurus plagiusa 5%

Gobiidae
Bollmania communis 2%

Serranidae
Serranus atrobranchus 14%
Diplectrum bivittatum 3%
Centropristis philadelphicus 2%

Synodontidae
Saurida brasiliensis 7%

Tetraodontidae
Sphoeroides parvus 3%

The above 11 species account for 80% of the individuals of fishes collected by Darnell with a 20-foot otter trawl on the Texas intermediate shelf. The remaining 20% of individuals are divided among an additional 37 species.

d. Outer Shelf Assemblage (Zone XXII). – The macro-invertebrates of the outer shelf are subdivided according to major bottom type.

Mud Bottom

Bivalves
Anadara baughmani
Eucrassatella speciosa
Pecten papyraceus
Cuspidaria ornatissima
Pitar cordata

Gastropods
Conus clarki
Natica canrena
Sconsia striata
Polystira albida

Sand Bottom

Bivalves
Microcardium transversum
Verticordia ornata
Lyropecten nodosus

Gastropods
Turritella exoleta

The ichthyofauna of the outer shelf assemblage shows a sharp reduction in diversity (only 23 species, as compared with 48 in the intermediate shelf and 61 in the nearshore shelf) but a corresponding increase in the numbers of individuals of the few species present. Thus only 3 species are required to account for about 80% of the individuals in this region: it required 10 in one and 11 in the other of the inshore zones.

Triglidae
Prionotus stearnsi 46%

Serranidae
Serranus atrobranchus 7%

Synodontidae
Saurida brasiliensis 29%

Bothidae
Syacium gunteri 3%

The above four species account for 85% of the individuals of bottom fishes collected in the Outer Shelf Assemblage. An additional 19 species possessed the remaining 15% of individuals.

The dominant species (in terms of individuals only) of demersal fishes in the three areas during the period May to July 1971 were:

Nearshore Shelf
(Zones IX, X, and XI)

Prionotus rubio
Blackfin Searobin

Cynoscion nebulosus
Spotted Seatrout

Polydaetylus octonemus
Atlantic Threadfin

Intermediate Shelf
(Zones XX and XXI)

Syacium gunteri
Shoal Flounder

Citharichthys macrops
Spotted Whiff

Serranus atrobranchus
Blackear Seabass

Outer Shelf
(Zone XXII)

Prionotus stearnsi
Shortwing Searobin

Sauridia brasiliensis
Lizardfish

Serranus atrobranchus
Blackear Seabass

3. Pelagic Organisms

a. Phytoplankton. – From a study of Gulf diatoms, Saunders and Fryxell (1972) believe that standing crop estimates are a reliable indicator of organic production in the Gulf. On this basis they conclude that inshore and estuarine waters of the Gulf are extremely productive, whereas open Gulf waters are considered to be relatively unproductive. Stations located 42 miles from shore contained 128 times fewer cells than stations 3-5 miles off shore. Studies of Saunders and Fryxell on diatoms (1972) and of Steidinger (1972) on dinoflagellates point to a relatively rich phytoplankton population on the Texas shelf. Some of the principal species among diatoms are *Chaetoceros compressum, Hemiaulus membranaceus, H. sinensis, Guinardia flaccida, Rhizosolenia alata, Asterionella japonica*, and *Skeletonema costatum.* Principals among dinoflagellates are several species of *Ceratium, Diplopelta, Dinophysis, Heteraulacus, Peridinium, Ceratocorys, Gonyaulax*, and *Pyrphacus.*

It is likely that the Texas shelf phytoplankton has an annual surge in organic production in early spring, followed by a summer low, and a secondary upsurge of productivity in the fall. Recent figures given by El-Sayed (1972) show that primary productivity is greater on the Texas shelf than to the east and south. Reasonable estimates place production values somewhere between 25-35 mgC/m^3/day on the shelf.

b. Zooplankton. – Much of the published work on the zooplankton of the Texas coastal waters has placed its principal emphasis on taxonomy and is therefore of limited value to the present study. There are, however, two important sources of data that minimize the seriousness of this deficiency. The first of these is the work of Khromov (1965) which shows the distribution of zooplankton biomass in most of the Gulf of Mexico. He shows a zone of low zooplankton density between Sabine and Galveston (Zone XI), but southwest of Galveston the nearshore density increases markedly. This may well reflect the contribution that the larval stages of shrimps make to the zooplankton in this region. Work with this group, carried out primarily by personnel at the National Marine Fisheries Laboratory in Galveston, provides the second valuable source of information on Texas zooplankton. Also, an inference may be drawn as to the richness of the Texas shelf zooplankton by the findings of Adelmann (1967) on chaetognaths. Collections for Adelmann's study were made off San Luis Pass in depths of 5 (Zone XI) and 16 (Zone XXI) fathoms. The chaetognath fauna was not only more diverse but also more abundant at the deeper station. Since chaetognaths are carnivorous, preying upon other zooplankters and fish larvae, it seems reasonable to assume that the zooplankton fauna on much of the Texas shelf is a rich one. Since some larval stages of shrimps are prey for chaetognaths, it is instructive to note the work on shrimp larvae on the northwest Gulf shelf carried out by Temple, Harrington and Fischer (1964). Collections were made on a regular basis between January and August 1962. *Penaeus* spp. (the commercial shrimp) made up 13% of the total 8-month catch of larval and postlarval *Penaeidae*. The density distributions of these larval and postlarval stages are shown in Figure A-34. The remaining 87% of the catch consisted of shrimp larvae of species still largely unexploited.

4. Marine Birds and Mammals

The nearshore shelf region (Zones IX, X, and XI) is habitat for a substantial number of bird species. Sandpipers, sanderlings, plovers, turnstones, willet, and godwits use the shoreline for their food supply during the fall (October-December) and spring (April-May) migrations. Sanderlings and willets depend upon these Gulf shores for their year-round existence.

The open water in the nearshore region is used as wintering habitat for the Red-breasted Merganser and Bufflehead ducks. Loons also frequent these open waters during November-April and feed upon the fish there. These birds would be seriously affected if these open waters of the Gulf and adjacent bays were not available to them. During the summer months the Gulf waters along the shores are used by black skimmers, gulls, terns and pelicans as feeding grounds.

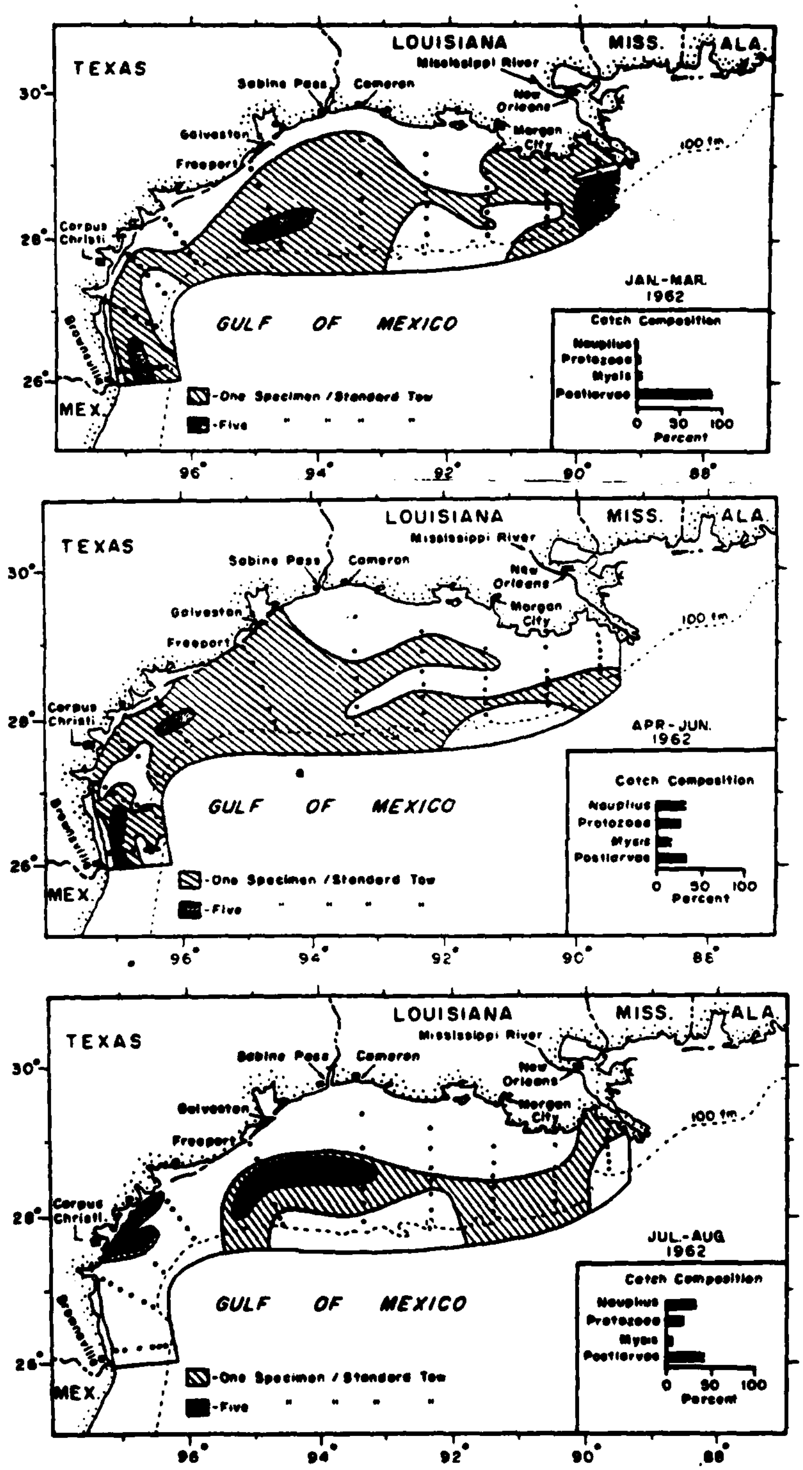


FIGURE A–34 DISTRIBUTION OF ZOOPLANKTON STAGES OF SHRIMP IN THE NW GULF (January to August 1962; after Temple, Harrington, and Fischer, 1964)

The mammalian fauna of Texas waters includes the West Indian Manatee, the West Indian Seal, and 16 species of whales or dolphins (Schmidly and Melcher, MS). The manatee and seal are either very rare or extinct. Reported sightings ceased in 1930. The season that most of the whales and dolphins use the coastal waters is not known (Brian Cain, personal communication).

D. MAN'S ACTIVITIES

1. General Information

Three major activities are pursued in the shelf waters of Texas. These are marine mining, commercial fishing, and sports fishing.

Texas and Louisiana areas have accounted for virtually all of the marine mining activity in the Gulf of Mexico. Up to now more than 99 percent of the Gulf of Mexico production has come from offshore Louisiana and the remainder from offshore Texas. New leases for mining rights off Texas are scheduled to be released for bid in February 1973. These sites are located beyond the shelf break in water nearly 600 feet deep. It is anticipated that the primary product at these sites will be gas-condensate, but some oil production will undoubtedly be developed as well.

2. Fisheries

Commercial landings of fish and shellfish into Texas ports in 1970 amounted to 146.9 million pounds (mollusks without shells) with a record dockside value of $53.2 million (Texas Landings, Annual Summary 1970, issued in 1971). This was 12.4 million pounds below the volume but $6.0 million above the value of 1969 landings. The menhaden fishery accounted for the volume decrease. The increase in value was in the shrimp fishery.

a. Shrimp Fishery. – Three species of shrimps are taken in Texas coastal waters, although a fourth (the rock shrimp) is beginning to attract the attention of some commercial operators. In 1970 the brown shrimp *(Penaeus aztecus)* accounted for 76 percent of the volume; white shrimp *(Penaeus setiferus)*, 22 percent; and pink shrimp *(Penaeus duorarum)*, 2 percent. The most important shrimp fishery is on shelf waters. In 1970, 59.1 million pounds were taken from Texas coastal waters and only 10.1 million pounds from its bays.

The brown shrimp tends to be concentrated in the intermediate shelf region between Freeport and Corpus Christi (Zone XXI) (Figure A-19). The white shrimp appear to be most abundant in the nearshore shelf region along much of the Texas coast (Zones IX, X, and XI), and especially in the grounds east of Galveston. This southern distribution of the brown shrimp is reflected also in the port landings (Figure A-9, for 1968). In 1970, Brownsville-Port Isabel and Aransas Pass-Corpus Christi handled 56% of the total Texas shrimp landings.

All three of the leading shrimp species spawn in the shelf waters, and the young (which are most susceptible to unfavorable environmental factors), aided by seasonal and tidal currents, make their way as postlarvae into the estuaries during the spring and summer months. Feeding, growth, and maturation take place largely in the estuarine and lagoonal nursery areas. In late summer and fall many of the new adults move back to the shelf waters. Smaller numbers of young may over-winter in the estuaries and pass outside in the spring. Both sexes migrate to the shelf spawning grounds where mating and egg-laying take place.

b. Crab Fishery. – The blue crab *(Callinectes sapidus)* is the only one of important commercial value. It is included here because it spends part of its life cycle on the nearshore shelf. It is here that the ovigerous females tend to concentrate. Upon hatching, the planktonic larvae pass to the lagoonal waters where they feed and grow to maturity. Copulation takes place in the estuarine waters, but the inseminated females move back to the shelf waters (Darnell, 1959). In 1970, 5.5 million pounds of crabs were landed in Texas (Texas Landings, 1971). Catches from Galveston Bay and Sabine Lake accounted for 60% of the state's catch – only 1% was taken in the Gulf proper.

c. Shallow-water Fishes. – Fishes of the menhaden, shad, mullet, sea catfish, and drum families spawn in shallow coastal waters – primarily in the nearshore shelf (Zones IX, X, and XI), but also in the intermediate shelf region (Zones XX and XXI). As in the case of the shrimps and crabs, the young make spring migrations into the lagoons. Summer feeding and growth periods are followed by mass migrations to the outside waters where reproduction takes place.

Most of the migratory coastal fishes are believed to live little more than two years. This means that each year's crop depends to a large extent upon the success of the previous year-class (Darnell, personal communication). An event that broke the sequence of dependency, such as a major oil spill, could create a void that would take the species involved years to fill.

Finally, mention should be made of the Red Snapper *(Lutjanus aya)* fishery, which is an open water fish, usually associated with reefs or some other structural feature in the environment. In recent years the snapper landings in Texas have been on the decline. For instance, in 1967, 1.4 million pounds were landed, whereas only 916,400 pounds were landed in Texas in 1970. Even so, in that year it was the second most valuable finfish product in Texas in spite of the fact that only four commercial snapper boats were operating out of Texas ports at the time. This does not reflect several hundred boats from Florida, Alabama, and Mississippi that frequent the rich fishing grounds off Texas (and Louisiana). The bank-dwelling snappers also figure very significantly in the coastal sports fishery. The sport-fishing efforts are confined largely to the nearshore regions (Zones IX, X, and XI and Zones XX and XXI), whereas commercial snapper fishermen utilize banks out to the edge of the shelf (Zone XXII). Among other fishes attracted to structures that are utilized by sports fishermen include groupers, amberjacks, crevalle jack, king and

Spanish mackerels, and barracuda. All of these may well appear around offshore terminals in large numbers.

E. ZONE IX – NEARSHORE SHELF (0-12 fm) RIO GRANDE TO CORPUS CHRISTI

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

Salinity	Annual average, 34.5 ppt (Figure A-21) Range, 30.0 ppt (April) to 36.5 ppt (August), (Figures A-22 and A-23)
Temperature	Lowest annual, 12-14°C (Figure A-24A) Highest annual, 29-30°C (Figure A-24B) Greatest range, about 18°C
Major storms	Average, 13 from 1900-1956
Width of zone	Average, 8 miles
Chief sediments	Sand
Turbidity	Low density
Shrimp populations	Brown, low density White, medium density Pink, low density
Demersal fish populations	Very low density

F. ZONE X – NEARSHORE SHELF (0-12 fm) CORPUS CHRISTI TO FREEPORT

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

Salinity	Annual average, 32.5 ppt (Figure A-21) Range, 24 ppt (April) to 36.5 ppt (August) (Figures A-22 and A-23)
Temperature	Lowest annual, 10-12°C (Figure A-24A) Highest annual, 30.5°C (Figure A-24B) Greatest range, about 20°C
Major storms	Average 17 from 1900-1956
Width of zone	Average, 12 miles
Chief sediments	Sands and muds
Turbidity	Moderate density
Shrimp populations	Brown, medium density White, high density Pink, low density
Demersal fish populations	Low density

G. ZONE XI – NEARSHORE SHELF (0-12 fm) FREEPORT TO SABINE PASS

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

Salinity	Annual average, 30.5 ppt (Figure A-21) Range, 22 ppt (April) to 34.5 ppt (August). (Figures A-22 and A-23)
Temperature	Lowest annual, 10°C off Freeport and 8°C off Sabine (Figure A-24A) Highest annual, 31°C (Figure A-24B)
Major storms	Average, 21 from 1900-1956
Width of zone	Average, 40 miles
Chief sediments	Sands and muds
Turbidity	High density
Shrimp populations	Brown, high density White, very high density Pink, low density
Demersal fish populations	Low density

H. TRENDS FROM ZONE IX TO ZONE XI (NEARSHORE SHELF)

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

1. Salinity decreases and runoff increases
2. Temperature range increases
3. Frequency of major storms increases
4. Width of zone increases markedly
5. Sediments change from predominant sands at Rio Grande to muds at Sabine
6. Brown shrimps increase
   White shrimps increase
7. Demersal fish populations increase

Compton (1965) conducted a bottom fish survey in the Nearshore Shelf Zone from Galveston to the region offshore from Freeport. He divided the collections into Zones about as we have (IX, X, XI). A total of 25,000 fishes were collected. They represented 89 species, but only 14 were common to all three zones. Two species were taken only in Zone XI and nowhere else, nine were taken only in Zone X, and 11 species were collected only in Zone IX. Some of the rarer searobins, goatfishes and eels prefer the more tropical water masses off Port Isabel. Comparing the catch between Zones X and IX (i.e., from north to south) Compton noted that the number of specimens per catch decreased, but the number of species increased.

Vulnerable Points

1. Pass Cavallo, because it is the northern gateway to the Aransas Wildlife Refuge with rare avian species.

2. Bolivar Roads Pass, because it is the entrance to the Galveston Bay complex, the most bioproductive of the Texas coast.

3. Seven and One-half Fathom Reef in Zone IX. High Scientific value.

I. ZONE XX – INTERMEDIATE SHELF (12-25 fm) RIO GRANDE TO CORPUS CHRISTI (SEAWARD OF ZONE IX)

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

Salinity	Annual average, 35.5 ppt (Figure A-21) Range, 34.5 to 36.5 ppt (Figures A-22 and A-23)
Temperature	Lowest annual, 15.5°C (Figure A-24A) Highest annual, 28.5°C (Figure A-24B)
Major storms	Average, 15 from 1900-1956
Chief sediments	Muds (Figure A-18)
Turbidity	Low density
Shrimp populations	Brown, high density White, low density Pink, low density
Demersal fish populations	Very low density

J. ZONE XXI – INTERMEDIATE SHELF (12-25 fm) CORPUS CHRISTI TO SABINE PASS (SEAWARD OF ZONES X AND XI)

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

Salinity	Annual average, 35.5 ppt (Figure A-21) Range, 35.0 to 36.5 ppt
Temperature	Lowest annual, 16°C (Figure A-24A) Highest annual, 29.5°C (Figure A-24B)
Major storms	Average, 17 from 1900-1956
Chief sediments	Alternating sands and muds (Figure A-18)
Turbidity	High density
Shrimp populations	Brown, very high density White, high density Pink, low density
Demersal fish populations	Medium density

K. TRENDS FROM ZONE XX TO ZONE XXI (INTERMEDIATE SHELF)

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

1. Salinity regime much the same.
2. Temperatures much the same.
3. Major storms show an increase.
4. Sediments get coarser.
5. Brown shrimp increase.
6. White shrimp increase.
7. Demersal fish populations increase.

Vulnerable Points

The most vulnerable entity here is the major concentration of shrimps in Zone XXI between Freeport and Aransas Pass (cf. Figure A-19).

L. ZONE XXII – OUTER SHELF ZONE (25-100 fm) RIO GRANDE TO MISSISSIPPI DELTA

Data applicable to zones on the shelf was included at the beginning of Section II. The following information lists those factors used to separate the reference zones.

1. Salinity

The surface salinity within Zone XXII averages about 36.2 ppt off the Rio Grande (range, 35 to 36.8 ppt); averages about 36.0 ppt off Freeport (range 35.5 to 36.5 ppt); and averages about 33 ppt west of the Mississippi Delta (range, 25 ppt or lower to about 36.0 ppt). Oceanic water having a salinity of more than 36.2 ppt penetrates along the bottom to about the shoreward limit (25 fm) of the Zone.

2. Temperature

Monthly temperature profiles taken south of Galveston in 40 fm of water show that isothermal conditions persist only during November-December. Harrington (unpublished MS) shows that at 50 fm this period is shortened to one month (December). Thus, the degree of mixing is far less here than in Zone XXI (immediately shoreward), with isothermicity in places of up to 6 months' duration. Bottom temperatures at 25 fm range from 14°C in December to 23° in May and from 29 to 21°C in the period from June to November. But at the 100-fathom isobath the December-May range is from 16 to 19°C, while the June to November range is 22 to 17°C.

Major storms	Average same as in Zones XX and XXI
Chief sediments	Muds to the southwest: mixture of sands and muds to the northeast. All muds along southern border

Turbidity	Very low density
Shrimp populations	Brown, high to medium density out to 50 fm, then zero White, low density to about 40 fm Pink, zero

3. Fish

A number of species of oceanic fishes visit the outer shelf (and may penetrate to the intermediate shelf) of Texas during the summer. These include some bill-fishes, dolphin, blue runner, mackerels (spanish, king, chub, frigate, and cero), bonito, tunny, amberjack, and several jackfish (horse-eye, bluntnose, crevalle, bar, and yellow). Darnell (personal communication) reports that he has observed large schools of bonitos and mackerel off Freeport in Zone XI, but for the most part they are only nomads in this region. While there, however, they prey heavily upon forage fishes and squids in the vicinity of passes into the embayments.

4. Vulnerable Points

The principal concern in much of Zone XXII is the hard banks that are covered with reef corals. This applies primarily to East Flower Garden, West Flower Garden and related banks (Figure A-20). These are of major scientific and recreational importance.

III. THE OCEANIC GULF (ZONE XXVII, 100-2100 fm)

A. INTRODUCTION

This zone begins where the bottom starts its uninterrupted bend toward the abyss. In the west it includes the deepest basin of the Gulf, the Sigsbee Deep, which is reputed to be the flattest area of appreciable size on earth. The basin's north and south walls are dominated by steep scarps, whereas its west wall supports a great system of parallel submarine ridges that run from Brownsville, Texas almost to Veracruz, Mexico. Here and there, to the south, the abyssal floor is interrupted by rounded diapirs, the Sigsbee Knolls, which are believed to be salt domes, and from one of which the oldest rock found in any ocean basin (carboniferous) was dredged by R/V *Alaminos* (Pequeqnat et al., 1971).

B. PHYSICAL CHARACTERISTICS

1. Hydrology

a. Temperature

The surface temperatures between summer and winter vary from an average of 27°C in August to 23°C in February. Highest temperatures may reach 31.7°C in August. A typical temperature-depth structure is shown in Figure A-35.

b. Salinities

Surface salinities are high, running about 36.2 ppt in winter and 36.8 ppt in summer (Ichiye, 1962). A typical salinity profile is shown in Figure A-36.

c. Currents

There are no strong, semi-permanent currents in this zone, but the patterns of winter winds and of winter circulation are much more clearly defined than the highly variable winds and currents of summer (Nowlin, 1971). From geostrophic assumptions, there appears to be a large, elongated gyre about over the Sigsbee Deep in the central western Gulf. Its major axis runs northeast-southwest, so that the current on the SE side of the gyre flows to the SW and the currents on the NW flow toward the NE. Velocities in the core of the latter have been calculated to be about 1 knot (Harding and Nowlin, 1966). For a more detailed picture of the surface circulation in the Gulf in summer and winter see Figures A-28 and A-30.

2. Chemistry

A dissolved oxygen profile for open Gulf waters is shown in Figure A-37. The double minimum is much more characteristic of the eastern Gulf, but is found in parts of the southwest Gulf.

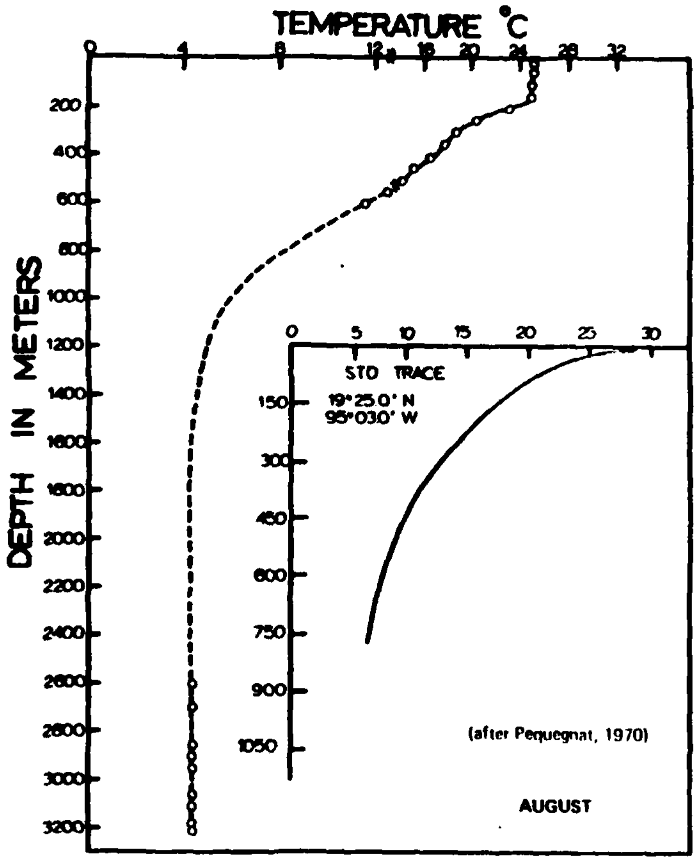


FIGURE A–35 TEMPERATURE-DEPTH STRUCTURE OF OCEANIC WATER IN THE WESTERN GULF

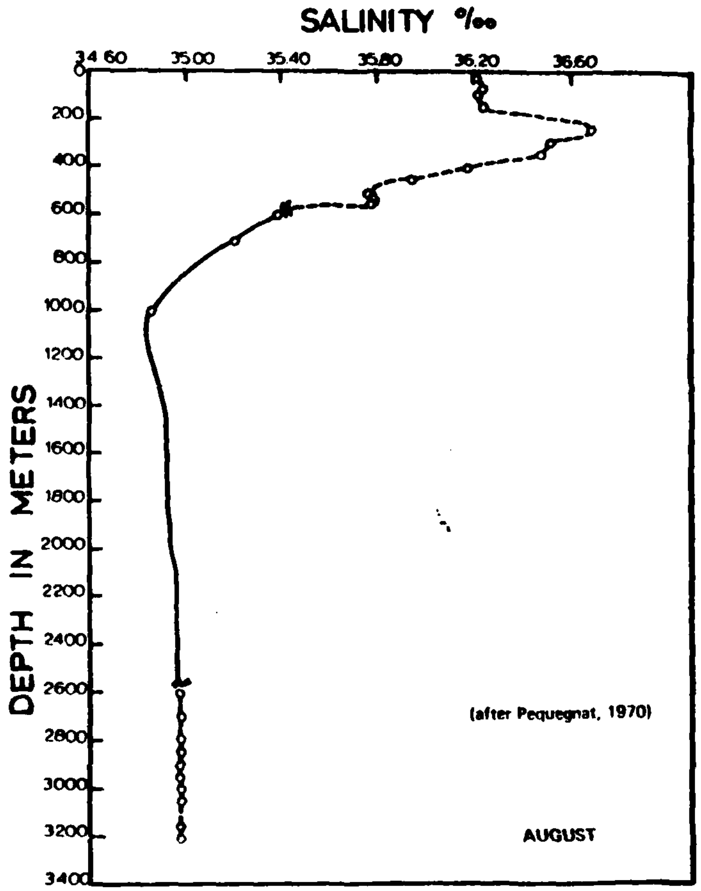


FIGURE A–36 SALINITY-DEPTH PROFILE OF OCEANIC WATER IN THE WESTERN GULF

Phosphate values in the upper 100 fathoms are higher in the central and western regions of the Gulf than in the east (El-Sayed, 1972). In the oceanic regions, phosphate values average 0.26 microgram-at./l, which is only slightly less than that found on the outer shelf, 0.27 microgram-at./l. El-Sayed (1972) found no consistent pattern of surface silicate values, but the trends were for higher than average values to be found along the western Louisiana and central Texas coasts, near the Yucatan Peninsula, and the central part of the western Gulf. Most of the values ranged between 0.50 and 20.0 microgram-at./l. Nitrate values increased from the shelf to oceanic regions. The values for surface waters ranged from 0.05 to 2.20 microgram-at./l.

C. RESIDENT AND TRANSIENT MARINE BIOTA

1. Phytoplankton

This oceanic zone appears to be one of low primary productivity, averaging about 6 mgC/m^3/day (El-Sayed, 1972). In line with this Saunders and Fryxell (1972) report that this zone does have a distinctive diatom flora, but that standing crop biomass levels are low. Typical of oceanic genera are *Ethmodiscus, Gossleriella,* and *Planktoniella* (Balech, 1967).

It has been reported that dinoflagellates are more abundant in open western Gulf waters than diatoms (Zernova, 1970). The most abundant genera encountered here by Zernova were *Pyrocystis, Ceratium,* and *Trichodesmium.* Whereas species diversity of dinoflagellates is greatest in offshore waters and decreases landward, cells per liter counts go up landward as does primary productivity.

2. Zooplankton and Micronekton

Four species of meso- and bathy-pelagic panaeid shrimps are reported from the oceanic zone of the western Gulf of Mexico: *Gennadas valens, G. capensis, G. bouvieri,* and *Bentheogennema intermedia* (Roberts and W. Pequegnat, 1970). The first and last of the above are most abundantly captured in oceanic waters (L. Pequegnat, 1972). The caridean shrimps are also commonly encountered in deeper oceanic waters, but the majority known from the oceanic Gulf are benthic (41 species). L. Pequegnat (1972) reports that the most common of the 22 pelagic species are *Acanthephyra purpurea, A. stylorostrata,* and *Systellaspis debilis.* Four species of mysidacean shrimps are also common enough in oceanic waters to be considered part of this assemblage: *Gnathophausia ingens, Eucopia australis, E. sculpticauda,* and *E. unguiculata* (L. Pequegnat, 1972).

The Euphausiacea are an important component of the zooplankton. James (1970 and 1971) reports that 32 species are known from the Gulf. *Euphausia mutica, Stylocheiron maximum, Thysanapoda pectinata,* and *Nematobrachion boopis* are common in epi- and mesopelagic oceanic waters of the western Gulf.

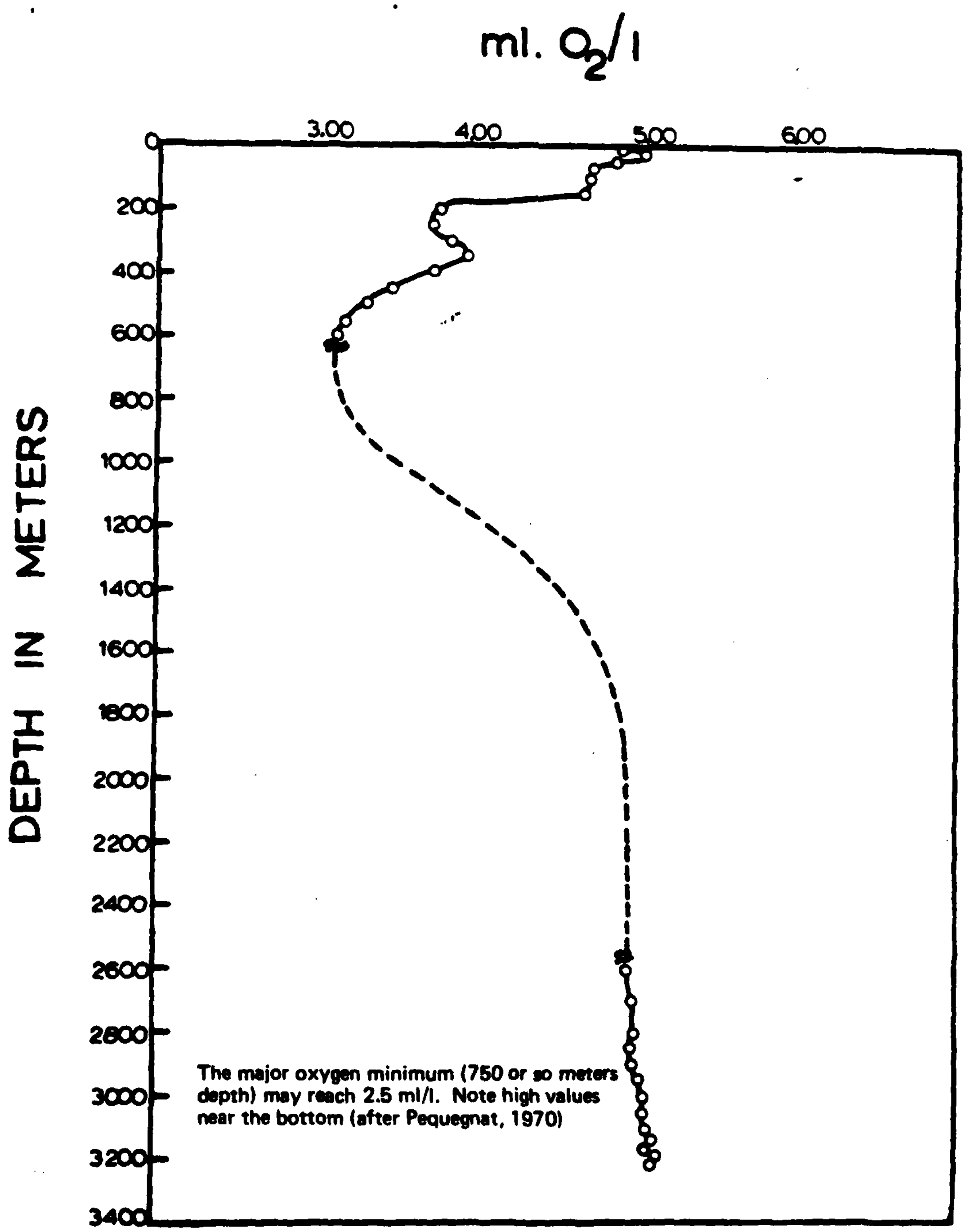


FIGURE A–37 OXYGEN-DEPTH CURVE OF OCEANIC WATER IN THE WESTERN GULF

3. Ichthyofauna

This is the realm of the pelagic fishes, especially those belonging to the family Thunnidae (tunas), and Histiophoridae and Xiphiidae (billfishes). The most important of the tunas in the western Gulf is the yellowfin tuna *(Neothunnus albacores)*, which is a warm-water species. Although the bluefin tuna is found in the Gulf, it is a cold-water species that appears in winter in the northern Gulf, particularly to the east. Other fishes of the oceanic region of the western Gulf are white marlin, blue marlin, swordfish, and sailfishes.

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